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A STUDY OF ENERGY IN A COMPLEX INDUSTRIAL ENVIRONMENT

VOLUME I:- MAIN TEXT

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

SUMMARY

Energy conservation techniques have been well established for a number of years. There appears to be no shortage of technical ideas. Resource shortages, higher costs and political pressures are compelling industry to use energy more effectively. With the means and incentives available, why then was there little impact within Fort Dunlop, a large UK tyre factory?

Modelling activities led to a number of analogies being drawn with energy consumption and conservation patterns. The initial product was definition of the "Diffuse Industrial User". Here consumptions are widely distributed over a large area, often constituting small flows in a complex system not feasibly monitored by conventional means. A number of definable problems emerged.

The first deficiency was awareness of energy usage, possible actions, and the need to improve. Publicity packages, backed by training schemes were implemented. Poor communication and lack of employee incentive were rectified. Discussion was given to improvements in the energy management structure, implementation of actions, energy accounting and purchases of primary energy. The key factors in formulating success reflected commitment, accountability and responsibility. However, there still remained an identification problem.

Economic and general impracticalities of monitoring every small energy flow in 'diffuse' distribution systems emphasised the need to establish alternative techniques. Studies began with a classical approach, the thinking extending to concepts of 'Energy Analysis'. Regression techniques were employed to derive performance consumption models. The basis for research, however, rested on the successful application of Thermography (an infrared remote scanning method). Conclusions suggested that whilst qualitative analysis was probable, quantitative results leading to energy balances were less certain.

Judged from these studies, it is unlikely that any single procedure could provide all the answers. The imput from thermography in a combination of methods must, however, be significant.

Michael Francis Gray

For the award of Doctor of Philosophy

March 1980

Key words ------------ "Energy Conservation Identification by Thermography"

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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.

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LIST OF PLATES - MAIN TEXT

LIST OF PLATES - APPENDICES

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

ACKNOWLEDGEMENTS

The complexity, volume and length of the research carried out together with the production of this thesis has demanded extensive cooperation and assistance from many people. The author wishes to extend his sincere appreciation to all who helped to consolidate this research; in particular:

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THESIS CLAIMS

1. From exhaustive literature surveys and studies of energy conservation techniques it can be concluded that there is no real shortage of technological imputs. The problems lie elsewhere.

2. Significant analogous models of energy consumption and conservation mechanisms have been produced.

3. Factories and industries having consumptions widely distributed over a large area, often constituting small flows in a complex system and not feasibly monitored by conventional means, are defined as 'Diffuse Users'. This is a new approach to classification of industrial energy users.

4. The problems facing successful implementation of energy conservation are: Awareness, Motivation and Incentive, Communications, Organisation, Implementation and Identification.

5. Partial solutions have been found to awareness, motivation/incentive, communication and organisation. Publicity, training and improvements to energy management functions have been implemented.

6. Identification of inefficiencies is significantly poor. Successful attempts have been made to study identification mechanisms and alternatives to substantial metering systems.

7. Performance models relating to Fort Dunlop consumptions have been produced from regression analysis of available data.

8. Remote sensing techniques, whether simple (snow-melt) or compound (infrared) are an effective qualitative solution to the identification predicament.

9. Quantitative analysis of heat loss by thermography, leading to production of energy balances, is less certain.

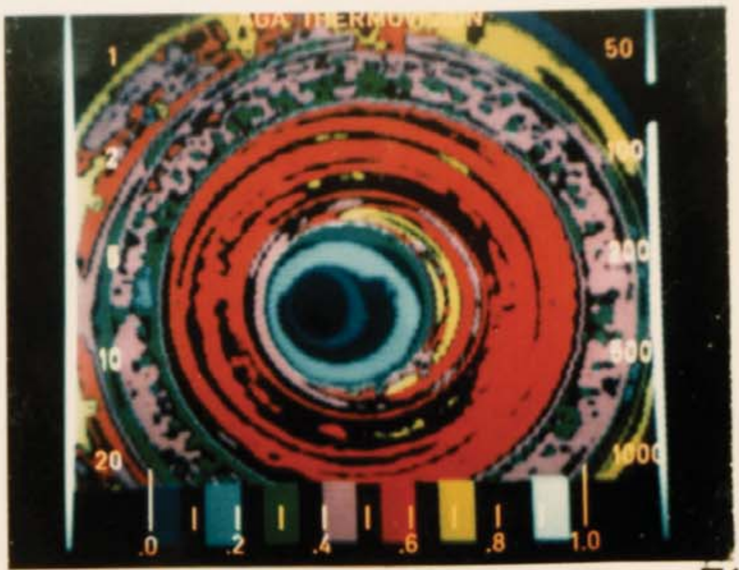
10. No single solution to the identification problem will predominate. Success is likely to lie in a combination of a number of methods amongst which Thermography will be significant.

THERMOGRAPHY - 'The study of remote sensing of temperature using total infrared radiation techniques'. (164)

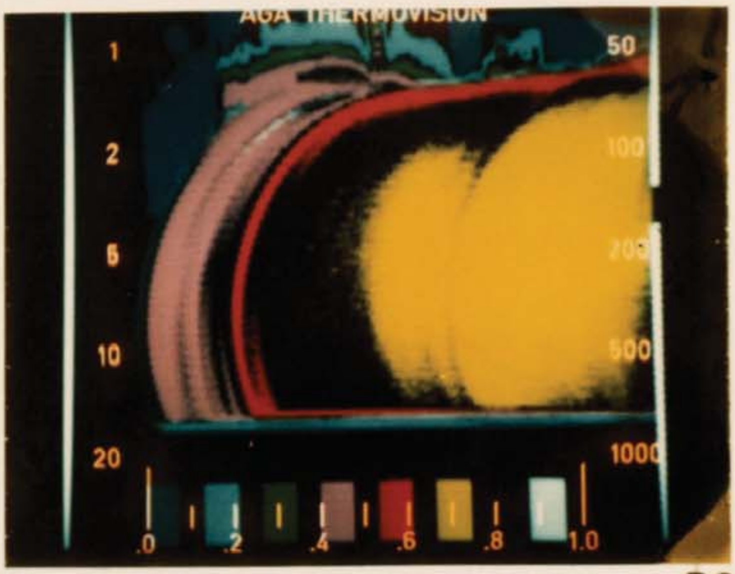
- See Appendices B,C,D and E for further examples and explanation of Thermograms.

- F1 ... non uniformity of temperature distribution in tyre moulds.

- D2 ... milling rubber: critical appraisal of temperature saves energy.

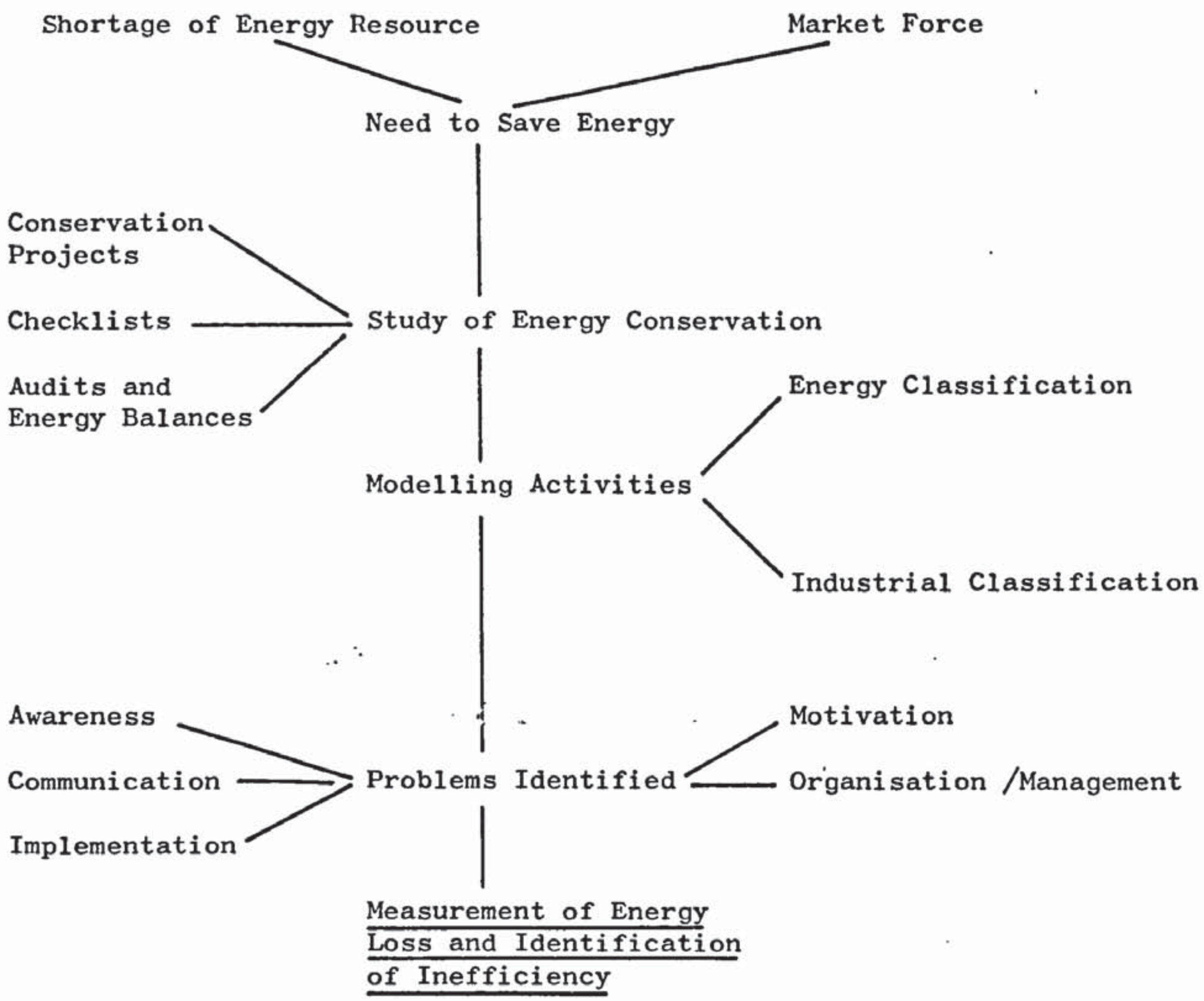


F1.



D2.

RESEARCH PATTERN



(A more detailed flow diagram is given in Chapter X, Figure 10.2.1.)

"There's husbandry in heaven;

Their candles are all out."

William Shakespeare
(Macbeth II i 4)

CHAPTER 1

ENERGY, CONSERVATION AND DUNLOP

1.1 Chapter Preview

Quadrupling of oil prices from the OPEC countries in 1973/74 brought about significant changes within British Industry. Emphasis was once again placed on the need to make more effective use of energy. This Chapter reviews the historical background to energy supply, demand and conservation relating to both Britain and Dunlop.

The major part is devoted to a critical appraisal of the pertinent literature on energy conservation policy, initiatives and actions. Account is given of the early part of the research leading to the compiling of a checklist and identification of the real problems facing conservation within Dunlop.

1.2 The Organisation Environment for the Research

The research described in this thesis was carried out while the author was employed within the United Kingdom Tyre Division (UKTD) of Dunlop Limited. The group constitutes the major part of Dunlop's manufacturing activities in the U.K., providing at the time some 60% of the total company sales. Figure 1.2.1 gives an indication of Dunlop's main activities in Britain, showing each division under the jurisdiction of four main groups, namely:

FIGURE 1.2.1

DUNLOP LIMITED MANUFACTURING ACTIVITIES STRUCTURE FOR THE UNITED KINGDOM

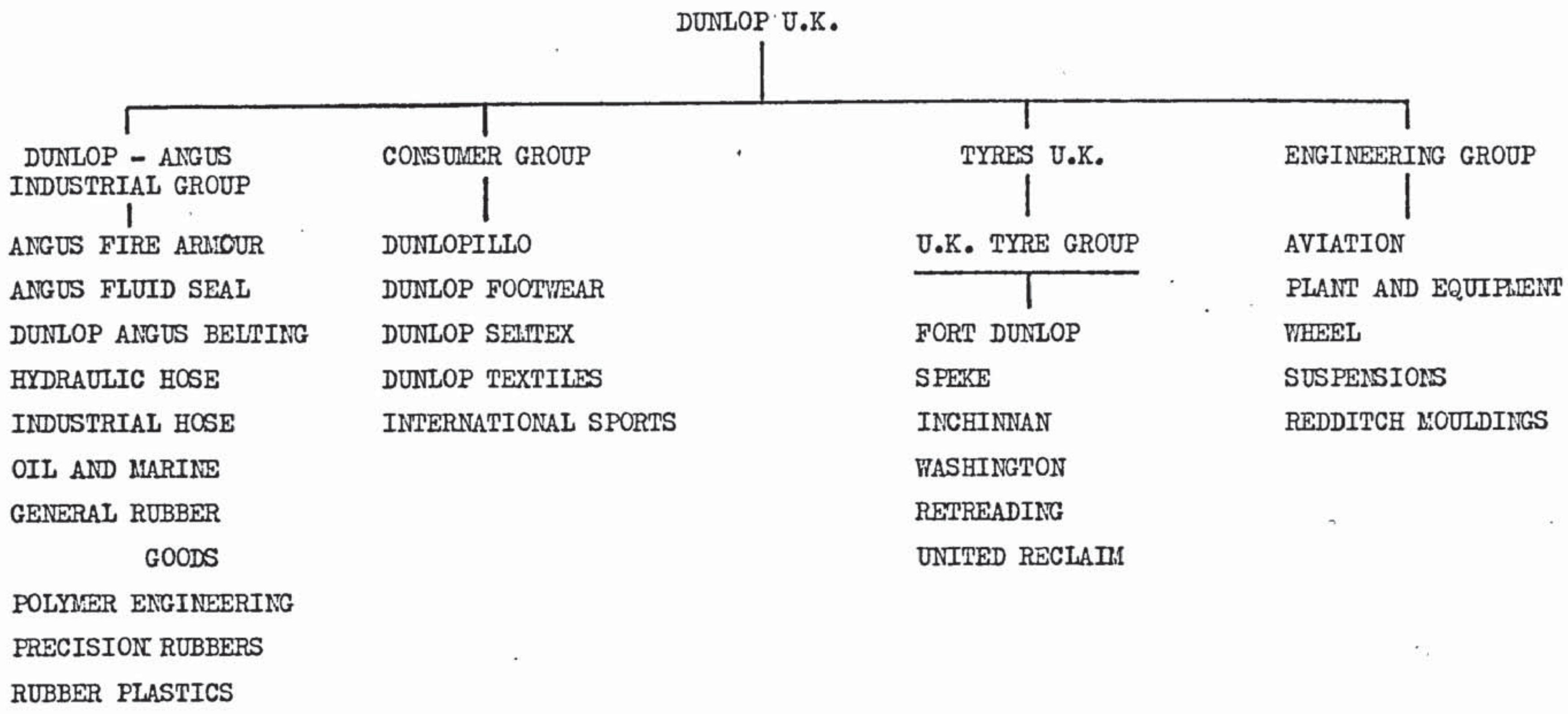


FIGURE 1.2.2

DUNLOP LIMITED, UNITED KINGDOM ACTIVITIES - PERCENTAGE SALES 1975

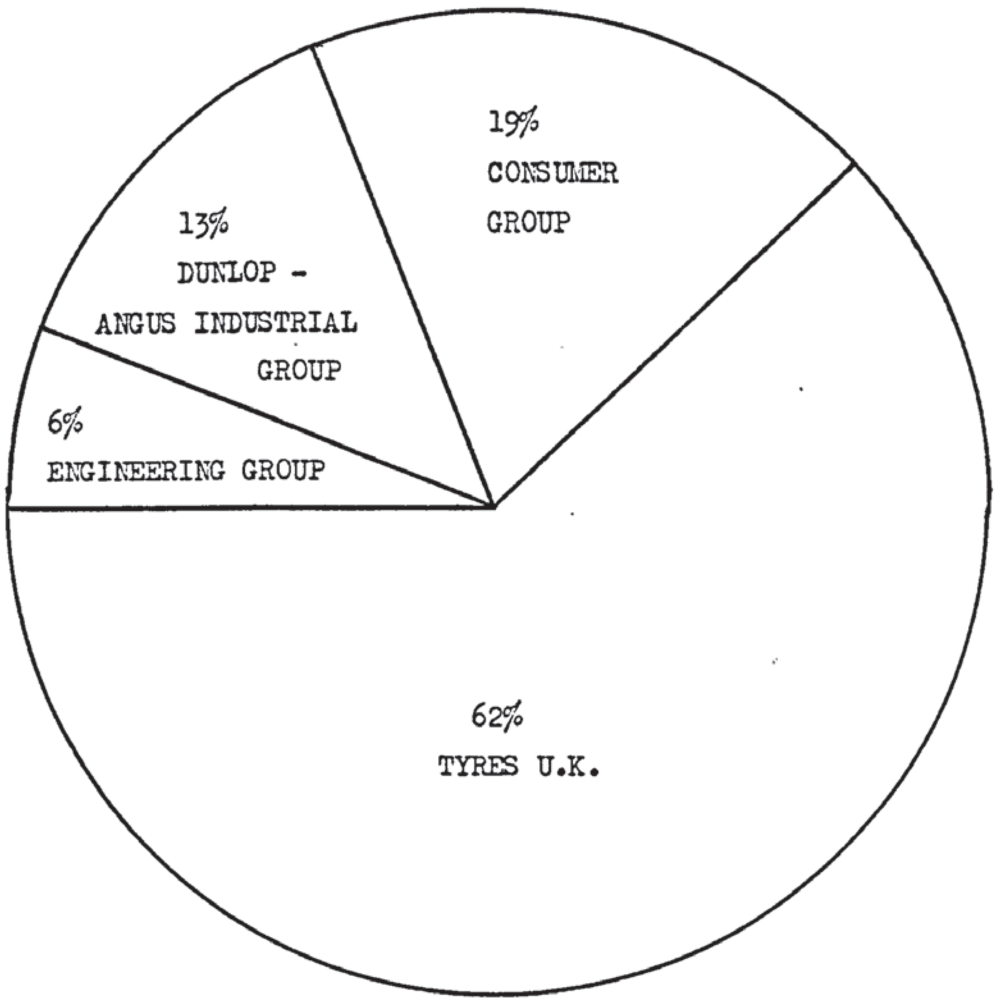
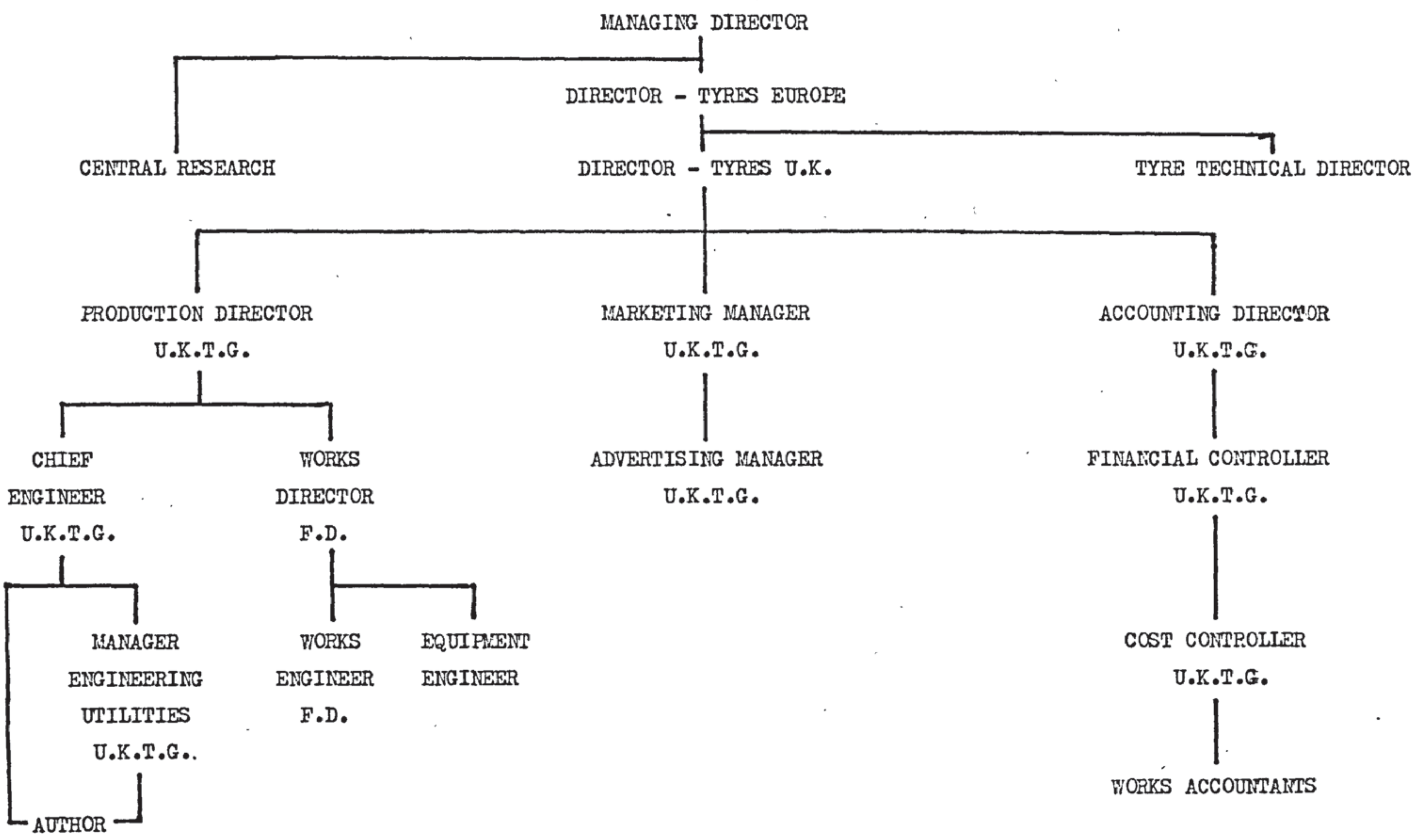


FIGURE 1.2.3

ORGANISATIONAL CHART FOR THE U.K. TYRE GROUP



Dunlop - Angus Industrial Group, Consumer Group, Tyres - U.K. and Engineering Group. The percentage sales turnover of each group, given in Figure 1.2.2., shows the relative size of each operation in Britain. The work was carried out for the Chief Engineer's Department, U.K.T.D.; shown in Figure 1.2.3. Close collaboration was also maintained with the Accounts, Marketing and Works Engineering Departments at Fort Dunlop in Birmingham.

The research formed part of the University of Aston's Interdisciplinary Higher Degree Scheme, Total Technology Option. Supervision was provided by a team of four, consisting of a chemical engineering main supervisor and a mechanical engineering associate supervisor, both of the University, and two industrial supervisors, namely the Chief Engineer, U.K.T.D., and the Manager of Engineering Utilities, U.K.T.D, (see Figure 1.2.3).

1.3 The United Kingdom Tyre Division

The United Kingdom Tyre Division (U.K.T.D.) contributes the largest part of the Dunlop company's annual turnover in the U.K. This turnover arises from both sales inside the country and from exports overseas. The group is engaged in the manufacture and marketing of a wide range of tyres and tyre accessories. As shown in Figure 1.2.1, it is divided into six divisions, four of which are tyre factories; namely: Fort Dunlop, Speke, Inchinnan and Washington. Fort Dunlop is the largest factory, having 57% of the groups tyre sales, and acts as the centre for the groups activities.

Washington factory is rated as one of the most efficient tyre factories in the world and is often taken as the standard for other operations. In contrast, the age and complexity of the Fort Dunlop operations initiated the majority of work to be directed towards this factory. Consequential results were, however, utilised throughout the group.

The research reported here has been concerned solely with the energy used in the making of tyres and associated products. This energy represents 29% of the total quantity of that consumed by manufacturing processes throughout the company. It is used in a variety of forms in differing quantities through a complex distribution pattern. Figure 1.3.1. gives examples of the types of energy used, showing gas, fuel oil, coal and electricity as being the major forms entering the factories.

1.4 Historical Background for Energy Consumption

Fuel and energy are considered to be one of the most important factors in the economy. Demand has risen appreciably since 1945, when there was a shortage of resource. Despite warnings from conservationists of possible "energy gaps" towards the end of this century, little attention has been paid to savings. Following a period between 1958 and 1962, in which oil was discovered and exploited in the Middle East, the price of oil fell, changing the emphasis of energy consumption towards petroleum. Together with the discovery of nuclear power, belief ran high that a limitless supply of cheap energy would always be available. This crippled any policy of conservation and caused a massive decline in the use of indigenous solid fuels in the U.K. With the coming of natural gas in the 1960's along with future prospects for North Sea oil, policy moved even further from conservation, cheap energy doing little but to increase consumption. The effect was to be noticed in the ensuing decade when the price of imported oil rose sharply. Through market forces, energy conservation along with resource depletion became important to both industry and the nation.

By demanding increased participation in their oil fields and co-ordinating their oil policy under OPEC (Organisation of Petroleum Exporting Countries), a transfer of control from the oil companies to the Middle East countries posed a political threat to the consuming countries. This coincided with an increasing dependence on the Middle East Block by the importing countries, of which the United States of America was now one. A price rise

FIGURE 1.3.1

TYPES OF ENERGY USED IN THE U.K. TYRE GROUP

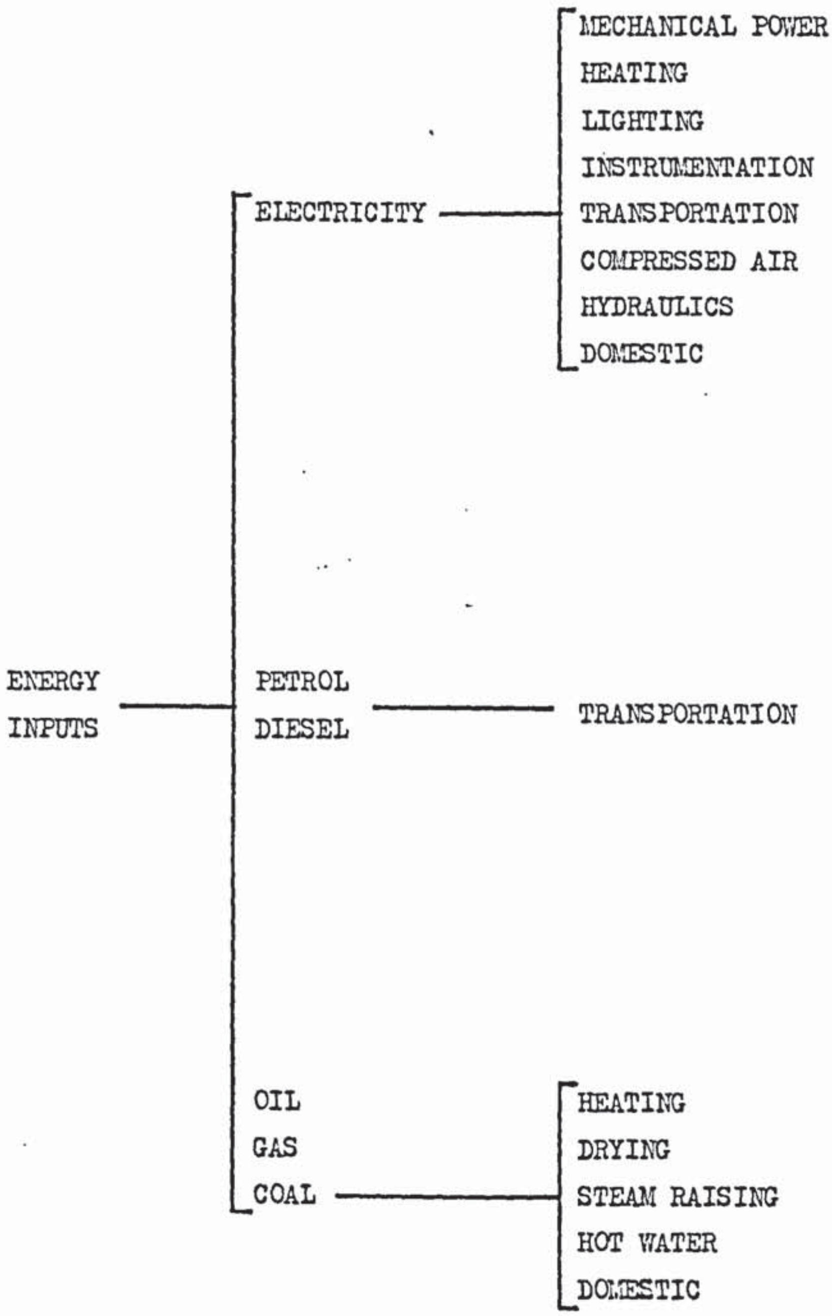
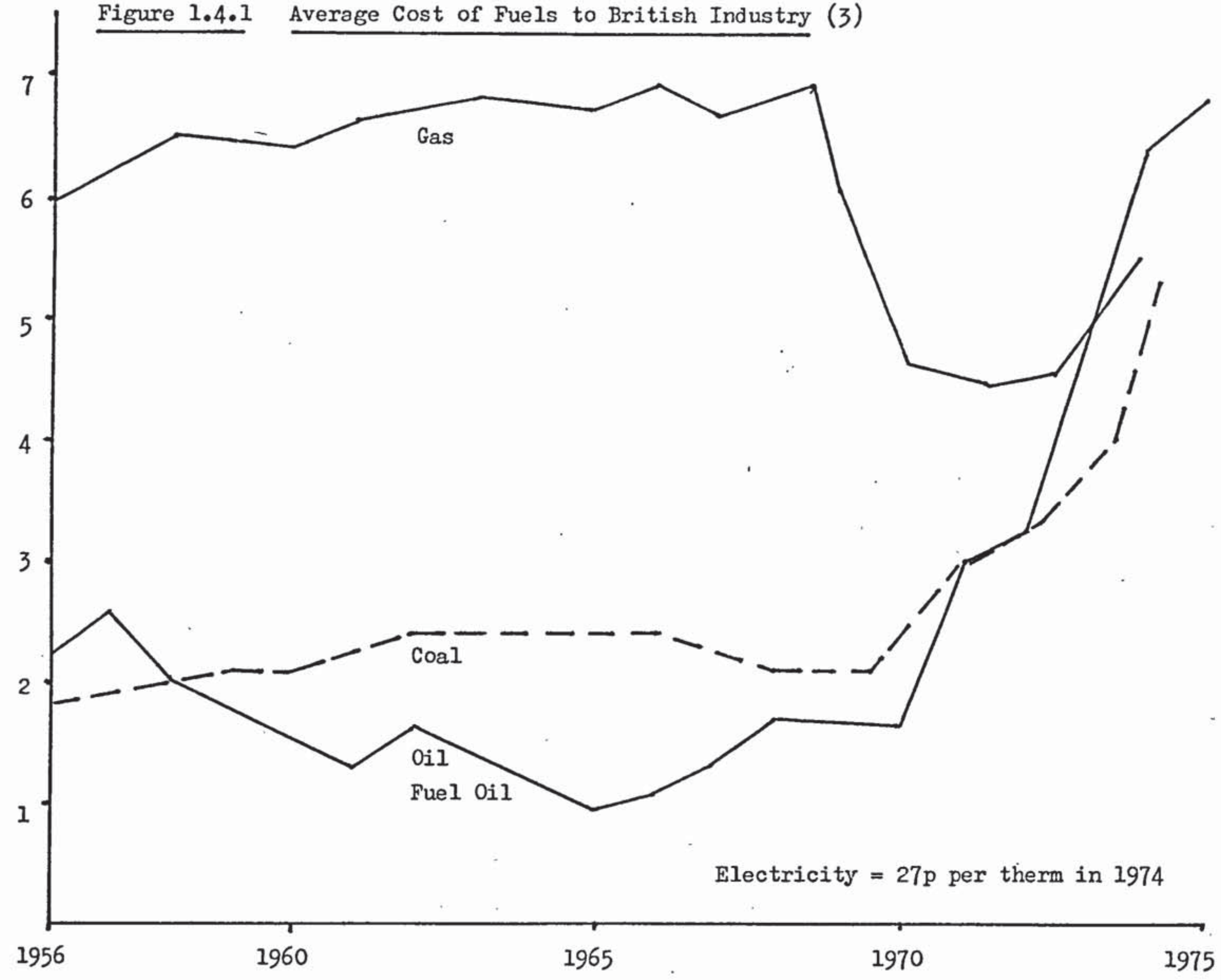


Figure 1.4.1 Average Cost of Fuels to British Industry (3)



was inevitable. (2). (See Figure 1.4.1 (3)). The quadrupling of the price of oil from October 1973 to early 1974 produced an income effect by transferring wealth from the U.K; and a cost effect by changing relative prices of consumer goods and services.

At the commencement of research, cost effects were not fully appreciated by industrial companies. It appeared that most expenses could be passed on to the final consumer. The impact of price rises tended to be dampened by the high value added by other costs and the fact that energy costs constituted only a small part of overall costs of production compared with labour and raw materials. (1).

The increased costs of primary energy, however, has since effected industry in two ways: (1)

(a) by increasing the cost of energy used within the industry - direct energy costs.

(b) by increasing the cost of materials used by that industry - indirect energy costs.

It is not the function of this thesis to discuss in detail past trends, future trends and effects of costs in concluding potential actions. Such discussions are well documented in the literature (1)(2)(7)(8)(10)(11)(12). It suffices to summarise what has gone before and what lies ahead in a few paragraphs.

The pattern of energy use in Britain's major industrial groups is given in Table 1.4.2. Two points emerge:

a) the iron and steel, chemical, cement and paper industries are the biggest consumers;

b) there has been a steady increase in consumption from 1960.

TABLE 1.4.2

ENERGY USED BY MAIN INDUSTRIAL GROUPS

	% OF TOTAL INDUSTRIAL ENERGY		
	1960	1965	1973
Engineering & other metal trades	17	17	19
Food, drink & tobacco	7	8	8
Chemicals & allied trades	13	12	17
Textiles, leather & clothing	8	7	6
Paper, printing & stationary	5	6	5
Bricks, tiles etc.	4	4	2
China, earthenware & glass	3	3	3
Cement	4	4	4
Other trades	9	10	13
Total 'other' industry	70	71	77
Iron & steel	30	29	23
Total for industry 10^9 GJ	2.7	3.0	3.8
Total for U.K. 10^9 GJ	6.2	7.0	9.3

Source : U.K. Energy Statistics

Electricity overheads for 28 % efficiency are included, other energy overheads are neglected.

Petrochemical feedstocks are not included in the above figures.

Single figures for the Rubber industry are not available from published statistics, estimates of the consumption for 1973 were put at 25 x 10^6 G.J. Over 80% of the rubber used was synthetic,requiring 71 G.J/Tonne to produce. General processing and manufacturing of products required little direct energy, approximately 45 G.J./Tonne for tyres.

Dunlop U.K. consumed 8 x 10^6 G.J. of the country's energy (9300 x 10^6 G.J. primary energy input) in 1973. In financial terms this represented about 3% of the company's annual expenditure, compared with 50% for materials and 30% for labour, and amounted to approximately £6m. These costs were divided as follows: (16).

Electricity	-	£3 + m
Gas	-	£1 + m
Oil	-	£1 m
Coal	-	£½ m

A more recent audit (307), carried out by the author in 1976/77, produced the breakdowns of consumption depicted in Figure 1.4.3. Figure 1.4.4. shows an extended subdivision to types of primary and secondary energy forms. No account was taken of the overhead losses accruing from conversion processes within the energy industries prior to input to Dunlop factories. Fort Dunlop is by far the largest single consumer in Dunlop U.K. representing approximately 29% of the total energy used by the company. For this reason the factory was chosen as the most likely area for potential improvement and the centre for research.

In 1960, U.K. Government policy was to replace coal consumption with nuclear power and oil supplies. The coming of natural gas in 1967 brought about a further change from a two to a four fuel economy - coal, oil, gas and nuclear/hydro power. Reversion to exploitation of indigenous fuels, chiefly North Sea Oil and gas, took place in 1970. The course of such events established significant changes in consumption patterns (Table

Figure 1.4.3 a

1975 BREAKDOWN FOR DUNLOP UK

Total Energy Consumption - 1000 GJ

DUNLOP UK (7989)

DUNLOP-ANGUS INDUSTRIAL GROUP (1542)		CONSUMER GROUP (1284)		TYRES UK (4402)		ENGINEERING GROUP (761)	
ANGUS FIRE ARMOUR	(?)	DUNLOPILLO	(313)	FORT DUNLOP	(2326)	AVIATION	(178)
ANGUS FLUID SEAL	(150)	DUNLOP FOOTWEAR	(144)	SPEKE	(989)	PLANT AND EQUIPMENT	(65)
DUNLOP ANGUS BELTING	(162)	DUNLOP SEMTEX	(299)	INCHINNAN	(567)	WHEEL	(434)
HYDRAULIC HOSE	(137)	DUNLOP TEXTILES	(260)	WASHINGTON	(130)	SUSPENSIONS	(44)
INDUSTRIAL HOSE	(118)	INTERNATIONAL SPORTS	(268)	REGENT	(243)	REDDITCH MOULDINGS	(24)
OIL AND MARINE	(93)			UNITED RECLAIM	(56)	HEADQUARTERS	(16)
GENERAL RUBBER GOODS	(550)			NATIONAL TYRE SERVICE	(91)		
POLYMER ENGINEERING	(231)						
PRECISION RUBBERS	(44)						
RUBBER PLASTICS	(57)						

ure 1.4.3 b

1975 BREAKDOWN FOR DUNLOP UK

ctricity Consumption - 1000 GJ

- DUNLOP UK (1468)
  - IOP-ANGUS USTRI'L GROUP (271)
    - US FIRE ARMOUR
    - US FLUID SEAL (54)
    - LOP ANGUS BELTING (9)
    - RAULIC HOSE (41)
    - USTRIAL HOSE (21)
    - AND MARINE (12)
    - ERAL RUBBER GOODS (74)
    - IR ENGINEERING (34)
    - CISION RUBBERS (14)
    - BER PLASTICS (12)
  - CONSUMER GROUP (257)
    - DUNLOPILLO (47)
    - DUNLOP FOOTWEAR (35)
    - DUNLOP SEMTEX (62)
    - DUNLOP TEXTILES (73)
    - INTERNATIONAL SPORTS (40)
  - TYRES UK (784)
    - FORT DUNLOP (322)
    - SPEKE (209)
    - INCHINNAN (76)
    - WASHINGTON (38)
    - REGENT (24)
    - UNITED RECLAIM (56)
    - NATIONAL TYRE SERVICE (59)
  - ENGINEERING GROUP (156)
    - AVIATION (39)
    - PLANT AND EQUIPMENT (4)
    - WHEEL (69)
    - SUSPENSIONS (26)
    - REDDITCH MOULDINGS (7)
    - HEADQUARTERS (11)

ure 1.4.3 c

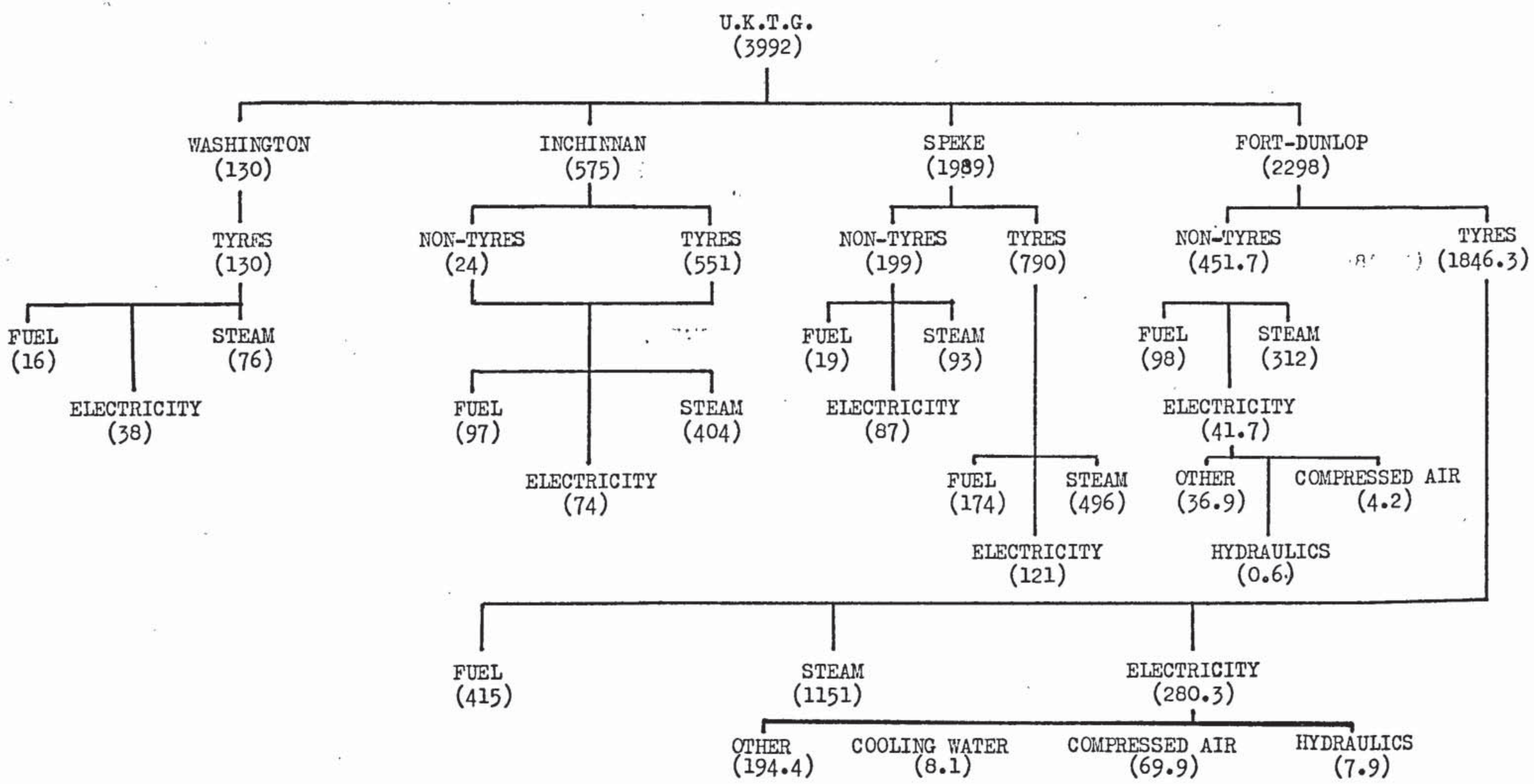
1975 BREAKDOWN FOR DUNLOP UK

l Consumption - 1000 GJ

- DUNLOP UK (6521)
  - OP-ANGUS USTRIAL GROUP (1271)
    - US FIRE ARMOUR (7)
    - US FLUID SEAL (96)
    - OP ANGUS BELTING (153)
    - RAULIC HOSE (96)
    - USTRIAL HOSE (97)
    - AND MARINE (81)
    - ERAL RUBBER GOODS (476)
    - IR ENGINEERING (197)
    - CISION RUBBERS (30)
    - BER PLASTICS (45)
  - CONSUMER GROUP (1027)
    - DUNLOPILLO (266)
    - DUNLOP FOOTWEAR (109)
    - DUNLOP SEMTEX (237)
    - DUNLOP TEXTILES (187)
    - INTERNATIONAL SPORTS (228)
  - TYRES UK (3618)
    - FORT DUNLOP (2004)
    - SPEKE (780)
    - INCHINNAN (491)
    - WASHINGTON (92)
    - REGENT (219)
    - UNITED RECLAIM (-)
    - NATIONAL TYRE SERVICE (32)
  - ENGINEERING GROUP (605)
    - AVIATION (139)
    - PLANT AND EQUIPMENT (61)
    - WHEEL (365)
    - SUSPENSIONS (18)
    - REDDITCH MOULDINGS (17)
    - HEADQUARTERS (5)

FIGURE 1.4.4

BREAKDOWN OF ENERGY CONSUMPTION IN U.K.T.G. (1975) - GJ x 10^3



1.4.5.).Whilst there appears to be much variation between industrial groups, there has been a substantial swing from coal to oil (13).

With consumption pattern studies relative to Gross Domestic Product (GDP) and compared with other nations (10)(11)(12) a number of points emerged. Energy growth rates bear close resemblence to those of GDP. Consequential growth in GDP would most probably be associated with increased energy demand on world supplies. Based on the assumption that "Third World" countries would themselves undergo economic growth, and faced with the prospect of dwindling energy reserves, the situation must emerge where too much money is chasing too little resource. At the time of commencement of this research, indications strongly emphasised the necessity to stretch resources in the U.K. by reducing consumption in all sectors of the economy.

Energy conservation had now come in a full circle from primary importance in 1945, owing to post war shortages, to renewed prominence by 1974. (3) (9). With renewed interest, Lyles systematic methods of saving energy (6) were reconsidered and formed the basis for the initial research in Dunlop.

1.5 Energy Conservation in the UK

Traditionally, it has been the energy intensive and high technology industries which have led the way to effective energy usage (121). In such cases it is possible to identify a steady improvement in efficiency - iron and steel, chemicals, rail transport etc. (8).

Improvements are often associated with fuel substitution; partly due to the new, more effective equipment installed and partly due to the more effective use of thermal input and flexibility of use (8). Many are, therefore, strongly dependent on investment, which may well decline with the fall off in growth in those areas (10h). Replacement offers

BLE 1.4.5

L SUBSTITUTION IN U.K. INDUSTRY

	% OF TOTAL INDUSTRIAL ENERGY INCLUDING IRON & STEEL		
	1960	1965	1972
n and steel :			
ing coal and products	18.9	16.6	12.0
-coking coal	3.6	1.6	0
l oil etc.	3.9	6.4	5.7
ctricity plus overheads (a)	3.0	3.8	3.7
(town and natural)	0.6	0.6	1.6
al	30.0	29.0	23.0
er industries :			
id fuel	35	25	11
	3	3	11
roleum	13	21	30
ctricity plus overheads (a)	19	22	25
al	70	71	77

rce : U.K. Energy Statistics.

) Electricity overheads are included on the basis of a constant 28% conversion efficiency possibilities of improvement but for many applications, good housekeeping, effective maintenance, streamlined operations and changes in attitude through better awareness may be the only feasible solution in the short term.

Whilst it was realised by many that conserving energy would not, in the face of growing GDP, offset the need for new resource discovery it would produce short term financial benefit. Should Britain establish consumption levels for the same economic activity compatible with other industrialised nations (10), conservation will have contributed much to restoring the balance of payments. Clearly the case is made for embarking on such a programme.

Three primary questions must be raised. (8)(53).

a) What are the areas of activity where there may be significant potential for energy conservation or the better use of energy? The ways in which energy is used in different sectors of the economy require examination with respect to patterns of consumption, social and technological changes.

b) Within these areas, what are the specific measures or alternative options that could lead to the better and more efficient use of energy? Past achievements must be studied to identify technical and social measures.

c) What are the procedures which could lead to a more precise identification of options, and secondly which relate these to actions? Analysis of how achievements were reached in the past and of the people who carried them out would indicate the directions for the future.

Incentive to save energy tends to be governed by political and economic policy. UK policy, has been based on the assumption that the higher energy costs will provide greater incentive to save. (8)(53) For those cases where costs cannot be passed on, this may be true (domestic sector), but within industry this premise must be questioned. The converse, however, is certainly true. Low fuel prices inhibit saving and increase inefficiencies.

Price alone is insufficient to bring about change. Technical and economic information must also be made available. Careful analysis is necessary when considering the options available; costs and benefits being balanced against the cost of energy supplies. This presents difficulties since decisions will often have to be taken on future forecasts.

Accounts of improvements made in the domestic, commercial, transport and industrial sectors are well documented in the National Economic Development Office (NEDO) publication on Energy Conservation in the United Kingdom (8). Estimation of potential improvement, is difficult since ambiguities exist in apportioning values to energy flows, making calculation of utilisation efficiency impossible. Industry does, however, consume 40% of the UK primary energy and must be a potential candidate for conservation contribution, albeit that capital investment will need to compete with other expenses.

From the iron and steel, cement, packing and chemical industries (8), many of the conservation techniques adopted by the remaining industrial sectors have emerged - integrated energy systems, material choice, optimum operation levels etc. It is not clear whether this is the correct approach. Differences can emerge between types of industry such as energy intensiveness levels and types of operations. These reflect the adoption of particular measures. Energy intensive industries for example, are likely to achieve their savings through capital intensive activities.

Energy conservation needs to be viewed with a rationalised approach involving co-ordinated studies and activities. Technological efficiency, economic effectiveness, environmental and social control are to be considered concurrently in decision making. The term commonly referred to as 'useful energy' relates to the efficiency of a specified closed system, which may exclude losses before or after that system. In real terms, it is, therefore, necessary to gauge overall efficiency by the ratio of 'useful' energy to gross primary energy. Unfortunately, in industry it is not always possible to analyse options on this criterion alone due to outside interference of market forces and other political factors. Conservation has obviously become complex and specific, requiring different approaches to problems and a clear understanding of the environment. Awareness of the need to save appears as a critical factor, apparently lacking in all sectors of the economy.

1.6 Review of the UK Government Policies and Actions

Considerations towards energy conservation have been a part of government strategy since the launch of campaigns to save fuel in the 1940's. The effects of the 1939-45 war and the event of a harsh winter in 1947 prompted the Ministry of Fuel and Power to set up mobile laboratories and teams of experts to visit industry with the aim of achieving higher utilisation efficiencies. It is not surprising, therefore, that the pressures of resource deficiency and high import costs for crude oil brought about renewed emphasis in 1973. The Department of Energy was formed, whose role it was to provide the incentive and technical information to save energy. Appendix F outlines the government's aims and actions.

Critical appraisal of the activities of the Department reflected a number of problems. Whilst the domestic and transport sectors showed improvement, industrial savings were slight, through companies being insensitive to the financial incentive and the provision of technical knowhow. For the most part, energy costs were low compared with other expenditure. Alternatively, knowledge of utilisation efficiency and effective control was lacking. In agreement with the author's findings, therefore, solutions needed to be found to improved identification, higher levels of awareness and better attitudes to energy use.

1.7 Summary of Action Checklists and Surveys

In carrying out the initial objectives of research it was necessary to survey as many of the technical procedures used in saving energy as possible. An extensive search of the current literature was made which, together with attendances of conferences and seminars (18) (67) (72) (73), were used to produce checklists (301-304). To list or discuss the merits of each source in turn would be time consuming and irrelevant to the main purpose of this thesis. It suffices, therefore, to name the major publications.

The search was based on 'The Efficient Use of Steam' (6) which provided a systematic approach to all heat savings. Although Lyles book was specifically related to steam and heat, many of the procedures were applicable elsewhere. A large proportion of the literature published after 1947 reflected these methods - 'Fuel Economy Handbook' (3), 'The Efficient Use of Fuel' (9), 'The Efficient Use of Energy' (74) 'Energy Saving in Industry' (20), etc. Similarly, many industrial organisations became involved in supplying equipment for achievement of these ends and in contributing to conservation successes by publicising their product. Spirax Sarco is one such company, having published comprehensive suggestions and providing the relevant equipment to back this objective (43) (49) (68).

Many consultant organisations have developed since the war ; ie. National Industrial Fuel Efficiency Service, originally backed by the government. These bodies provide advice to industry as well as being actively engaged in training programmes, seminars and extensive publication (3). Likewise, Industrial Research Associations, Government Research Establishments, Universities and other professional bodies have produced a mass of specialised techniques for saving energy and studying energy flow patterns. Included amongst these are the large consumers such as British Steel and the energy industries (Shell, B.P., British Gas and the C.E.G.B).

The checklists, based on the subdivision of categories shown in Figure 1.7.1 and based on the general procedures shown in Figure 1.7.2, were prepared for energy saving campaigns at Fort Dunlop and other factories within the Dunlop organisation.

It is realised that not all measures are applicable to a specific industry or factory. As with most checklists, the recommendations must be adapted to the climate of that particular location. In certain industries, there may also be distinctive information appertaining to that environment. These have been included. Likewise, omissions are possible since the subject of conservation is extensive. It can be said with certainty, however, that there appears to be no shortage of technical procedures. The reasons for the non-realisation of potential savings in industry are, therefore, not due to lack of technical knowhow. The solution to the problem lies elsewhere.

1.8 Energy Conservation in Dunlop

1.8.1 Historical Account

Generation of energy saving projects in the U.K.T.D. was commonplace even before the 'Energy Crisis' of October 1973. The number, however, had been restricted by financial considerations. The largest savings at Fort Dunlop came during the period 1969 to 1971 with the installation of a new boiler house. (309). The inefficient, coal fired, steam raising operation was substituted by modern Babcock & Wilcox dual oil/gas fired F.M. boilers. A reduction of specific fuel consumption by 10 MJ/kg resulted. (See Figure 1.8.1). It is likely, however, judging from the fact that such a low specific consumption has not been achieved since 1971, at least one third to a half of the saving resulted from the plant being new and efficient, only part being attributable to the substitution

Figure 1.7.1

SUMMARY OF CHECKLIST

1. Avoid excessive use of any energy.
2. Avoid leaks of any kind.
3. Avoid idle operation of equipment.
4. Make use of exhaust heat.
5. Attempt to integrate energy systems.
6. Ensure maximum efficiency of equipment.
7. Ensure maximum efficiency of use and operation of equipment.
8. Ensure good insulation is used and maintained.
9. Avoid the use of electricity for heating.
10. Carefully monitor and control energy flows.
12. Assess all projects financially.
13. REDUCE usage of energy to a minimum.
14. Keep up to date with technological and financial changes.
15. Never be afraid to tell someone of an idea for saving energy.
16. Reorganise work schedules for employees.
17. Reorganise production layout and machine use for maximum efficient energy use.
18. Design all systems, equipment and buildings with energy in mind.
19. Remove availability of individual manual control and use of energy.
20. Energy Sense is common sense so save it!

Figure 1.7.2

SUMMARY OF CLASSIFICATION OF CHECK LIST

PROCESS	- HEATING
	- PROCESS & PLANT OPERATION AND ORGANISATION
	- INSULATION
	- POWER
	- DESIGN
	- PROCESS WASTE
BUILDING	- HEATING
	- LIGHTING
	- VENTILATION
	- OPERATION
	- INSULATION
	- DESIGN
	- DOMESTIC HOT WATER
TRANSPORT	- OPERATION
	- MAINTENANCE

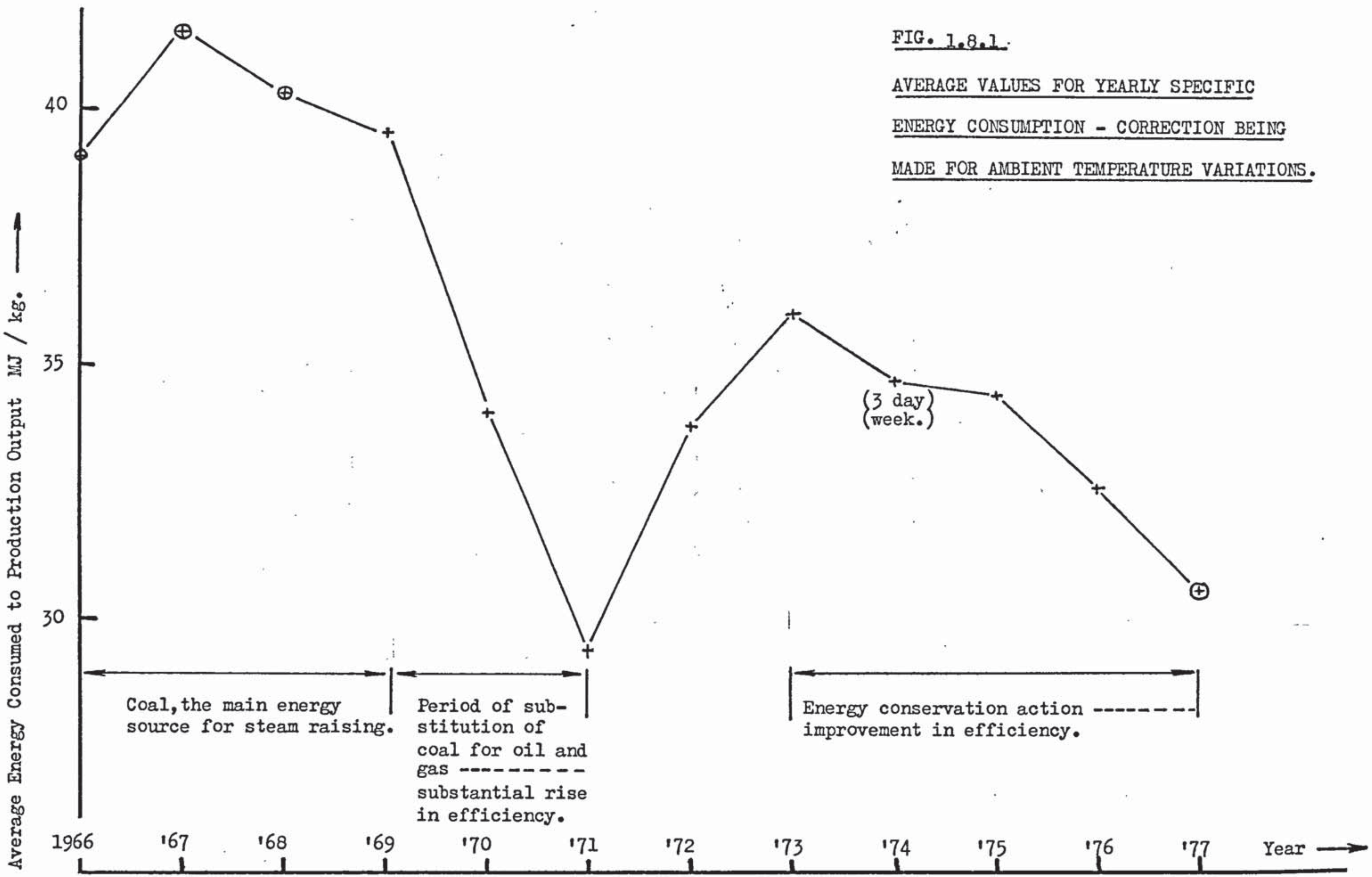


FIG. 1.8.1.

AVERAGE VALUES FOR YEARLY SPECIFIC ENERGY CONSUMPTION - CORRECTION BEING MADE FOR AMBIENT TEMPERATURE VARIATIONS.

itself. This emphasises the point that although gas is easy to handle, is burnt at high efficiencies, and is generally a better fuel, substitution without higher maintenance standards is insufficient.

Following the events of 1973, energy saving campaigns received greater impetus resulting from economic and political pressures. Table 1.8.2. outlines the progress made over the ensuing years.

Direct energy costs in Dunlop are small compared with other expenditures. In the past this, along with the complex nature of the distribution energy (mostly in small quantities), provided little incentive to optimise the use of energy. Emphasis tended to be placed on production efficiency and output. In 1974, however, large gains in cost savings were thought to be possible. Levels of 30% reduction by 1980 were quoted for the U.K.T.D. For 1974 and 1975, targets were put at the more conservative figure of 10% (94)(97). From the outset it was recognised that senior management participation was necessary for the Energy Conservation campaign to have the required impact. Responsibility for energy conservation in U.K.T.D. was given to the Chief Engineer, responding to a committee consisting of members of the Management Committee - Director, Tyres U.K.; Finance Director; Production Director and Director, Tyre Technical H.Q.

The management of the campaign was based upon traditional concepts:-

a. Evaluate the possibilities.

b. Organise a management structure and allocate responsibilities.

c. Set objectives.

d. Monitor performance.

e. Regular review

The author was employed to investigate each of these.

TABLE 1.8.2 PROGRESS OF DUNLOP ACTIONS AND POLICY

1969-71	-	Commissioning and Installation of New Boiler House.
		1972
Mar.	-	Proposal to modernise Fort Dunlop Services (89) in particular steam distribution. Results of energy and water survey.
Jul.	-	Commencement of energy balances and steam efficiency comparisons for UKTD.
Nov.	-	Collection of energy consumption data for non-UK factories.
		1973
Oct.	-	'Energy Crisis'
Dec.	-	Survey of steam services, Fort Dunlop (95). Losses and distribution problems highlighted. Propose: steam main, condensate recovery and maintenance.
		1974
Jan.	-	Three day week - higher efficiency of energy usage.
Feb.	-	Report on effects of Energy Crisis on Dunlop (16); the need for an energy policy; better control, maintenance and investment; suggestions on savings; and the possible reversion to coal.
Mar.	-	Segregation of conservation activities UKTD into; short (lagging), medium (operation/process) and long term (investment/plant and equipment).
Apr.	-	Realisation that attitudes, lack of awareness, motivation and analysis difficulties present problems. (97). Recommendation that energy conservation be responsibility of a senior manager but not through central control. Target to reduce energy bill by 10%.
	-	Chief Engineer appointed head of working party for UKTD with works engineers responsible for energy in individual factories.
	-	First major energy conservation meeting identifying savings for Fort Dunlop (lagging, steam main, control, operating techniques, design and heat recovery). Investigation of Tariffs.
	-	Energy Conservation investment budget set up.
	-	Layout produced for actions required and targets for each factory.
	-	Survey of Inchinnan services.
	-	Survey of Buffalo, USA factory services (92)
May	-	Appointment of Manager of Engineering Utilities to co-ordinate energy conservation in UKTD.
	-	Experimental determination of steam wastage and implementation of maintenance programme (87).
Jun.	-	First fuel audit for Fort Dunlop (96)
	-	Computerised control of maximum demand for Dunlop Hanau (91)
	-	Basis for savings calculations and setting up of regular monthly consumption reports established.
	-	Energy committees set up in all factories; co-ordinated by manager of engineering utilities.
	-	Experiments carried out in cure control and mould design.
	-	Inter-factory comparisons for energy based on specific consumption per unit weight of product.

Table 1.8.2(b)

Jul.	-	Appointment of author to study energy consumption patterns and conservation possibilities.
	-	Investment programme for improved condensate recovery.
Aug.	-	Formation of energy action plan (101).
	-	Completion of Fort Dunlop Energy Balance for 1973 (338).
Sep.	-	Investigation of Total Energy Schemes (314) (315).
Oct.	-	Survey of Dunlop, Montlucon services (90).
	-	Report on 1974 savings for UKTD.
	-	Establishment of need for 'Energy Wardens' on the shop floor.
Nov.	-	Commencement of experiemental improvement of press efficiency in Tyre 5 (88).
	-	Devising of departmental performance information and recording system for UKTD factories.
	-	Setting of 1975 management plan for saving energy.
Dec.	-	Publication of likely technical and engineering actions to save energy (69).
		1975
Jan.	-	Reports published on lighting levels (99), steam transmission and losses (316) (317) (318), disposal of combustible scrap (108).
	-	Site energy separated into production and non-production usage with the formation of a new accounting system (100).
	-	Motivation of energy saving appears to be the problem.
Feb.	-	Production of checklists (301) (302) (303) (304).
	-	Completion of boilerhouse energy balance (339) (342).
	-	New monthly consumption reports compiled.
	-	Measurement and control of energy with sufficient accuracy appears to be a problem.
Apr.	-	Attitude survey on energy conservation completed at Fort Dunlop.
Jun.	-	Appraisal of incineration of tyres (319).
	-	Experimental incineration of tyres in cupolas (320).
Oct.	-	Savings for 1975 estimated.
	-	Management plan for energy conservation in 1976 to 1978 completed.
	-	Targets set for 1976-1978.
Nov.	-	Dunlop energy conservation check tree (83).
	-	Production of paper on the problems facing energy conservation in this type of industry (121).
		1976
Jan.	-	Production of 1976 programme (94) for energy saving in UKTD.
	-	Investigation of feasibility of fluid bed fired boilers for Dunlop (125).
	-	Publicity, posters and stickers introduced (130).
Feb.	-	Commencement of Dunlop UK energy audit (307).
	-	Commencement of UKTD publicity project (328).

Table 1.8.2(c)

Mar.	- Setting up of statistical analysis of energy wage (341) (342). - Tables of costs of energy usage and losses for Fort Dunlop Buildings and equipment compiled (324) (325) (326) (327).
Apr.	- Breakdown of energy usage in UKTD and Fort Dunlop for publicity purposes. - Production of energy training scheme.
May	- Publication of UKTD conservation programme and its successes (94).
	1977
Jan.	- Completion of publicity campaign package for Dunlop.
Feb.	- Launching of Mr 'Save it' (331) - Remote sensing of energy losses through snow melt (344). - Preparation for Thermovision experiments (345).
Mar.	- Analysis of energy trends for Fort Dunlop and UKTD (306) (343). - Advertising of Publicity campaign throughout Dunlop (332) (334).
Apr.	- Second publicity/press report (333).
May	- Third publicity/press report (335).
Jun.	- Second energy audit of Fort Dunlop (96) - metering and accounting of energy questioned. - Fourth publicity/press report (336)
Jul.	- Re-appraisal of Incineration (321).
Aug.	- Fifth publicity/press report (337).
Sept.	- Report on predictions of availability of types of primary energy for Dunlop - coal is most likely form (309).
Oct.	- Trial exercise for energy training programme (330).
Nov.	- Presentation of energy conservation problems in Dunlop (313).
Dec.	- Re-appraisal of Total Energy - MEB for Fort Dunlop.

The effect of indirect energy costs were not considered at the time but in the light of more recent reports, these could be significant. Increased energy and feedstock prices might lead to a rise in costs of synthetic rubber production of the order of 50%. (1). In 1973, 60% of the consumption of rubber in Dunlop was accounted for by synthetics. The cost of materials and energy were, therefore, expected to undergo increases; the percentage of turnover attributed to fuel and power more than doubling by 1980. (16).

Obvious sources of loss were tackled at once whilst the overall potential was being evaluated. Projects involving the author are listed in Table 1.8.3.

Actions continued throughout 1975 with little real reduction in specific energy consumption (1.6MJ/kg of product). With the setting out of the formal management plan on energy, however, the campaign gained additional impetus, reducing the specific consumption by a further 4.0MJ/kg by December 1977, (See Table 1.8.4).

This brought the percentage reduction in energy use since 1973 to 15.6%. Actions, including the substitution programme in 1970, reduced energy consumption by 22.8%. realisable as an £824,000 benefit to the company, (based on 1977 costs).

1.8.2 Evaluating the Possibilities

The prime objective of the energy campaign was not to control energy as such but to control its increasing costs. The evaluation of energy actions involving investment and the accounting of energy flows in Fort Dunlop and other factories was thought to be no different from standard procedures. Allocation of costs against departments and products, however, required review. Accounting

Table 1.8.3.

List of Specific Projects Undertaken by the Author (323)

1. Survey of steam services, Fort Dunlop (317)
2. Procedure for calculating economic lagging thickness
3. Heat transfer from plant and equipment
4. 'Total Energy'
5. Verification of illumination levels.
6. Financial appraisal of conversion of a conventional boiler to fluidised combustion (125)
7. Fort Dunlop energy conservation checklist (303)
8. Study of UKTD seasonal energy trends for 1975 (305)
9. Fort Dunlop energy statistics trends 1966 to 1976 (306)
10. Dunlop UK energy audit (307)
11. Fort Dunlop gas prices and trends (309)
12. Incineration of scrap tyres and waste material (319)(320)(321)
13. Fort Dunlop energy balance - year ending 1973 (340)
14. Boiler house energy balance and efficiency verification (341)(344)

Note: This list does not include those projects which have been included in some detail within this thesis.

TABLE 1.8.4

Specific Energy Consumption Improvements 1969-1977

Year	Specific Consumption * MJ/kg	Saving MJ/kg
1969	39.5	-
1970	34.0	5.5
1971	29.4	4.6
1972	33.7	(4.3)
1973	35.9	(2.2)
1974	34.6	1.3
1975	34.3	0.3
1976	32.5	1.8
1977	30.5	2.0

Total Saving since 1969 = 9.0 MJ/kg (22.8% Reduction)

* These figures include correction for temperature (See Chapter 8). No account is taken of production output variation - 1972/73 having the largest volume.

( ) Indicate negative saving.

periods did not coincide with suppliers' metered accounts, upon which factories relied for their prime input data. It was, therefore, necessary to install extra monitoring capacity from which data could be collected and resultant consumptions assigned to specific cost centres.

Extra meters were installed, either permanently or temporarily, in order to check these allocations. It was often difficult, however, to justify the cost of new meters. Apportioning systems were also inaccurate and often misleading in detail. It was, therefore, accepted in the absence of anything better, targets and energy efficiency monitoring based on regular allocations would be used. Clearly this was still unsatisfactory.

Sorting out the energy cost and use figures was done by engineers and accountants. As a result, UK Tyre Division now had a standard system for regular reporting of energy use and costs in the four major factories.

Water, although not strictly an energy charge, was included not only because it was a commodity of increasing cost, but also because it was a sensitive indicator of energy loss. Most water was and is used for heat transfer, either for steam conversion, hot water plants or for cooling systems. Identification of abnormal water consumption was believed to be a suitable pointer to energy waste.

During evolution of monitoring consumption, certain areas of high energy use were exposed. Amongst these was the inefficient use of compressed air, realised as being one of the most expensive energy commodities. It was also found that outside the regular maintenance and investment programme, employee motivation ranked high on the list.

1.8.3 Management Structure

Energy management in UK Tyre Division did and does work in three ways: (94)

a) Each factory has an Energy Manager, functionally responsible for factory effort. He is usually the Works Engineer or Services Manager. These are not necessarily the most suitable. Successful Energy Managers in other companies have been drawn from Production, Work Study and Accounting functions.

b) Each Production Departmental Manager is responsible for his own energy use and costs along with all other costs. Some factories have appointed additional energy wardens.

c) Non-factory departments having a positive role to play have nominated personnel to co-ordinate their own efforts - Tyre Technical H.Q., Publicity Department etc.

This structure reflected the established line responsbilities within factories and manufacturing departments. At the same time it provided a specialist functional lead and a backup from supporting organisations.

1.8.4 Targets

With the knowledge gained by 1975, detailed targets were written into the 1976-78 Management Plan (103):

a) Factory targets for specific primary and secondary energy consumption were set. The required levels were based on performance data from Dunlop tyre factories in UK, Europe and USA.

b) This was extended to departmental targets for steam, electricity, air and water usage.

c) The factory Capital Plans included approximately £300,000 for energy conservation investment for the period 1976-78.

1.8.5 Performance Monitoring

Overall energy use, cost and savings was reported each month to the Factory Manager, Production Director and Chief Engineer. Works Accounts monitored departmental consumption and costs, reports being available for weekly Production Manager's meetings. The effectiveness of this last system is questionable since part of the basic data used was either incorrect or derived from estimates.

Capital projects were evaluated and monitored through traditional channels, forming regular discussion points at UK Tyre Division progress meetings. In addition to factory activities, regular meetings were held with technical and publicity departments, although no formal documentation of these reviews exists.

1.8.6 Energy Conservation Measures

At an early date, it was established that there were no difficulties in finding things to do. Every major authority in Europe had prepared energy checklists. A general checklist, however, was addressed to tyre plants (83); listing also the management checks used for control. The basis policy was:

a) tackle simple things first and keep them simple

b) go for savings which were not people dependent

c) improve control - install time clocks and thermostats

d) isolate plant when not required

e) optimise production activities - reduce overtime working

f) optimise machine and building utilisation

g) establish possible technical improvements (69) (94)

h) establish possible engineering improvements (87) (88)

Action plans were prepared for the factory engineering, personnel, marketing, production and technical functions. (94). At a later stage the Author contributed a more comprehensive checklist (303).

1.8.6 Employee Motivation

Initial energy conservation measures employed designing the "man" out of the system. Since a high correlation exists between energy use and the number of manhours spent in both direct production and non-productive activities for this type of industry, later efforts included actions aimed at improving employee awareness and understanding of energy matters.

A publicity campaign was launched in March 1977, shortly followed by a training programme. This was based on a social survey of employee attitudes towards energy (122). The programme also superseded several unsuccessful attempts to improve employee's attitude to energy usage. (130) (94).

The basic objectives of both the publicity and training campaigns were to create a greater awareness of energy resources and usage, thus clarifying the need to conserve. The ultimate aim was to produce a suitable attitude towards energy. This is discussed more fully in a later Chapter.

Publicity and training alone, however, were insufficient criteria to affect a permanent attitude change. Clearly additional incentives were required to obtain any significant improvement. Employee motivation, both at shop floor and senior management level, became another major requirement.

1.9 The Initial Project Specification

The project was set up at a time when energy conservation was being considered in every major sector of British industry. Triggered by the Middle East events of October 1973, in a relatively short time the price of oil imports had quadrupled producing both a real transfer of wealth from the U.K. and a change in the relative price of consumer goods and services for the future. (1). Despite the fact that Britain seemed better off than most, with indigenous supplies providing security for the immediate future, industry was faced with the prospect of rising costs of production. Those industries, in which energy costs contributed a large part of production expenditure, were the first to acknowledge this change by initiating conservation actions. Others, such as Dunlop, in which the total fuel bills were large, soon followed their example.

As a result of initial investigations and reports produced within the company, a directive to save energy was passed from the Dunlop Head Office to the U.K.T.D. At that time, conservation procedures had been considered in the group for a number of years but without the same impetus. In April, 1974, working parties were initiated, under the control of the Chief Engineer of U.K.T.D. These included immediate actions involving little capital expenditure and better control, medium term actions in changing the process, and long term investment in new plant. In May, 1974, the author was appointed to carry out a detailed study of energy in the Fort Dunlop factory and to make the necessary recommendations for conserving this energy. The work commenced in July, 1974.

Energy conservation is defined as 'the better and more efficient use of energy with proper regard to the related costs and benefits at that time'. (8) (53). Saving energy in circumstances involving a disproportionate cost in other resources should not be considered, whether these be economic, social or environmental. It appeared from the literature that technical knowledge was sufficient, the problems lay in implementation. (5). The initial objectives, therefore, were to collate as much technical know-how as possible, by which energy savings could be made.

Market forces, technical and economic information alone appeared insufficient for success. The second objectives, therefore, were to provide good communication channels through management and to identify broad areas where actions could be taken. Such recommendations had already been made by a report from the Ministry of Fuel and Power in 1972 (15). In general, a co-ordinated approach to energy conservation was needed, involving economic technical and social aspects.

By 1975, having established that a significant quantity of technological know-how on energy conservation was readily available, it was difficult to understand that with the Dunlop initiative, energy savings were still relatively small. The following difficulties were put forward as possible reasons:-

a) poor employee attitudes to energy

b) poor measurement leading to unreliable data

c) the need for improved analysis techniques in determining energy efficiencies.

d) lack of commitment and responsibility in management

e) lack of energy-campaign continuity.

f) ineffective means for detection of energy loss

Identification of energy usage and potential savings constituted the major part of this research. It became clear that present systems of analysing energy consumption in certain complex areas were not always accurate. Energy distribution in this type of industry appeared to have small quantity flows over a large network. Metering flows was not always economical and alternative methods needed to be found in order to monitor the effects of savings. Devising a solution to this problem constituted the major part of the research.

CHAPTER II

MODELLING ENERGY USE IN INDUSTRY

- THE PROBLEM IDENTIFIED

2.1. Chapter Preview

Obvious difficulties exist in producing positive energy usage improvements in certain industries in Britain. Fort Dunlop is a typical example of a factory having a poor track record. It is necessary to divulge the reasons for this negative progression. This chapter reviews a series of models developed to analyse the industrial system and to highlight subsequent problems. Particular emphasis is given to 'Diffuse Users', such as the Rubber industry, in an attempt to improve energy efficiency in Dunlop.

2.2. Conservation Incentive - A Problem?

To determine whether it is possible to significantly reduce demand for energy by improving the efficiency of utilisation; extending knowledge of the processes, which is ultimately responsible for fuel consumption; and by increased efficiency with which fuels are used in these processes, cannot be the only consideration.

Contrary to mythical beliefs that saving energy is a function of technology and engineering alone, successful conservation in industry appears more akin to a combination of economical, sociological and political constraints. Evidence of significant levels of technology is well established (303) and is sufficient to produce marked improvements in energy use for the short term period. This of course is not to say that improvements in efficiency of processes, or plant and equipment are not possible in the long term. Clearly both play their part. The question remains, however, why industry has failed to make use of existing technical know-how to maximum advantage in using energy more effectively.

Whilst many simply dismiss the lethargy towards adoption of energy conservation in industry as being a simple consequence of cheap fuel, it is also evident that making this commodity more expensive is not the whole answer. Reflecting the cost trends for Dunlop and the country as a whole (1) (309), any immediate activity brought about by the 'Energy Crisis' has been both ineffectual and short lived in real terms. Clearly there is need to identify which factors influence energy saving in the Company. Solutions may best be attained through modelling activities.

2.2.1. Standard Techniques For Energy Conservation

Energy conservation requires a formal, systematic and co-ordinated approach. A sound structure needs to be employed, upon which the search for savings and the following actions can be made. Activities have so often been haphazard in the past that potential savings have not been exploited to the full. The problem appears in defining the areas in which the investigation takes place and in implementing saving techniques.

2.2.1a. <u>The Lyle Approach</u> (6)

This method formed the basis for energy conservation in the UK in 1947 and is still applicable today. It suggests a three step approach; at the same time continually increasing the available knowledge, depth of technology and extent of investment up to some limit. According to Lyle the heat balance is the key, requiring a few simple measurements and estimates. There is often some difficulty in carrying out a sufficiently accurate balance, since monitoring of consumption is not always economically possible. Distribution networks may be ill defined and complex in nature, making measurement of energy flows impossible and pure guesswork (6).

The balance can be achieved by studying bills, meters and reports, the data from which will go to produce a quantitative flow diagram or Sankey diagram (9). From this target levels can be established as an indication of what ought to be used. This target or 'bogey' is not an immutable figure but must be constantly advanced and updated as techniques improve and better plant becomes available. Such levels should be set by experienced, unbiased personnel. Lyle advocates that 90% of steam-using factories can save 25% of their steam in two to three years as a result of carrying out a heat balance. He rightly suggests that it would pay factories using large quantities of fuel to employ permanent staff to study heat balances. Improvements in efficiency will of course depend on the present state of the plant and will become harder and more expensive to achieve with the passing of time.

Once substantiated and the 'bogey' produced, the three-step approach can be implemented.

a. Primary heat saving - This usually takes place while carrying out the balance and in setting the 'bogey'. It involves little investment. Following the 1974 crisis,these activities have often been referred to as 'housekeeping procedures' (lagging of pipes carrying heated fluid, eliminating leaks, maintaining equipment, etc).

b. Reduction of work to be done - Process and plant modifications are often needed to reduce work done by steam or other forms of energy. In certain cases operational changes alone may provide the savings. Lyle suggested such modifications as: lowering process temperatures, reducing reprocessing and cycle times, maximising load factors, etc.

c. Tackling waste heat collection - Work here is likely to require investment, often incorporating detailed financial analysis. It involves heat recovery from secondary losses such as engine exhausts, flash steam, condensate and evaporated vapour.

Lyles theories need not apply simply to steam and heat, but cover a wide range of energy forms. The energy balance, however crude, must form the basis for any conservation measures. In poor plants, alternative means must be sought to produce measurements on which the balance can be made. Many plants lie in this category and cannot simply be dismissed as being 'impossible'. Monitoring of savings can easily be achieved by using the balance itself.

2.2.1b. The Government Approach

Given the commitment and managerial organisation, the next step in a company is to determine the energy requirements, so as to assess the steps needed to save energy, and to measure the success of the energy saving programme (20b). The whole success of conservation rests on a representative energy balance which may in practical terms be difficult to achieve, particularly in low energy intensive industries.

Assuming usage is known and flows can be monitored, the government recommendations are:

a. Primary energy savings - good housekeeping.
b. Reduction of waste heat.
c. Improvement of efficiency with which energy is used.
d. Reduction of waste or recycled product.
e. Increased factory output (20b) (20d).

The procedure laid down is a logical progression of the Lyle System. Areas of high consumption should be examined and the resulting actions, based on cost-benefit assessment, should be the product of co-ordinated discussions with management, engineers, technologists and trade unions. Once completed, the savings must be monitored and the targets reset. Re-examination of results for further improvements, both short and long term, can then be carried out using internal expertise or external opinion if necessary. The use of expert advise is strongly recommended (20).

The basic differences between this approach and Lyle rests entirely with greater co-ordination and involvement of all disciplines. More emphasis is placed on suitable attitudes in management and amongst employees, greater control of energy flows, and improved auditing techniques. The effectiveness of the published recommendations, however, remains to be seen.

2.2.1c. Alternative Approaches

A. For Lyle, the background was one of energy shortage and rationing. To save energy in any way possible was beneficial. Since 1947 situations have changed with emphasis being placed on different things. Approaches have therefore altered; for example more activity is taking place in attempting to change people's attitudes, rather than simply invest in new plant or carry out process modifications (8) (20). For example energy related aspects now include: (121).

a. Explicit problem solving methods through systems analysis and work study.
b. Techniques in calculation of losses including effects of inflation.
c. Improved control systems involving computers and microprocessors.
d. Improved thermal data.
e. Alternative energy source/generation technology.
f. Behavioural knowledge advances on attitudes, etc. including methods for motivating actions and industrial psychology.
g. Economic awareness and information on time effects, inflation and finite resources etc.

B. In most of the literature surveyed, Lyle's approach remained the basis for saving activities. In some cases this had been extended, for example, the division of heat recovery into direct and indirect

(41). Similarly, primary and secondary losses have an intrinsic difference (Fig. 2.2.1.). Primary losses should not be tolerated at all and can be tackled immediately as a result of simple observation. No plan is required. Secondary losses, however, require some need for thought and require planning based on a heat balance or some other technique (65).

In a publication 'Fuel Saving in Industry' (46), P. Tate suggested a division of savings by energy usage patterns, namely - air heating, water heating, metal heating and power. Subdivision of each of these then followed: water heating:- use, transmission and generation; and power:- motors, compressed air and lighting. The technique has advantages of being simple and therefore easily implemented. A second approach relating to use is through efficiency. Classification according to the levels of efficiency in a plant may be possible in industries having clearly defined systems of energy flow. Difficulties are likely to occur in low energy intensive industries. For greater effectiveness, these methods can be taken one stage further by considering energy as a function of the process, building or transport (44).

C. A third approach, involves human behavioural patterns and activities. It is believed by many that the route to effective savings in the short and long term is by way of attitude changes (8) (20) (46) (54). Attitude surveys could well lead to the identification of a more meaningful classification of potential conservation procedures. This creates a climate through awareness and incentive, for the implementation of required technical measures. Another aspect of this category is the study of usage through activity levels. Savings could be identified with the levels of the man-hours worked

FIG. 2.2.1

PRIMARY AND SECONDARY HEAT LOSSES.

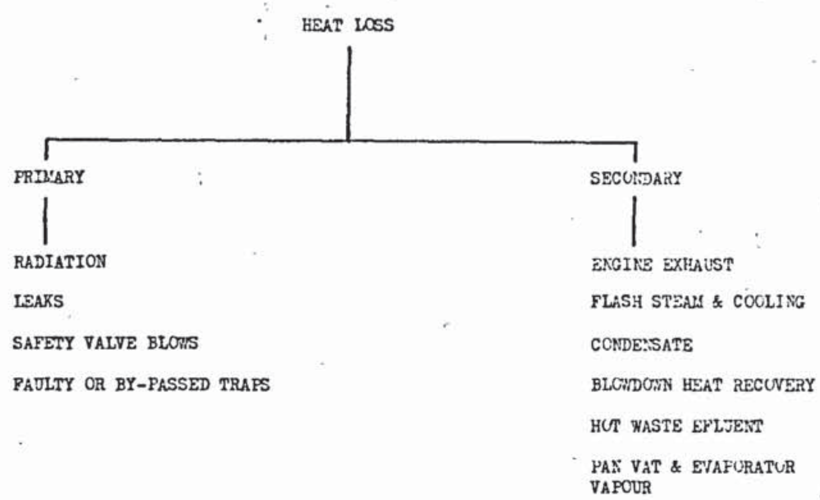
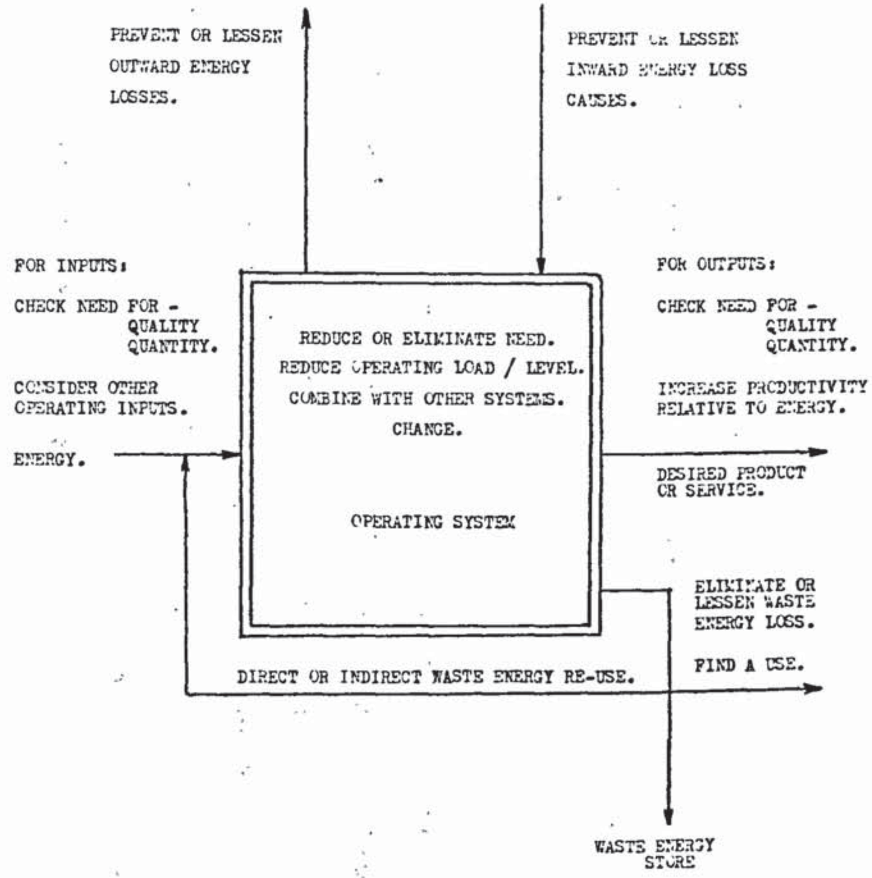


FIG. 2.2.2

GENERAL ENERGY SAVING APPROACHES



to give a priority listing. Studies of this nature are of particular significance in publicity campaigns. Industries having poorly monitored energy use but relatively high labour intensiveness provide the most probable candidates.

Whatever the approach adopted, analysis of energy flow or some alternative is the first priority. This also requires a knowledge of theoretical consumption levels from which comparisons can be made. Sophisticated measurement is not always necessary, but a formal recording system of essential flow is recommended for efficient control. Records can indicate not only potential savings but also the success of the actions taken.

2.2.1d. Process Building and Transport Segregation

Energy consumption may be broken down into functions of processing (P), building (B) and transport (T). The overall consumption can be expressed as a function of these within the confines of the immediate control of that industry:

$$\text{Total consumption} = f(P,B,T,)$$

The energy used by the process function is that energy consumed specifically in production and other subsidiary activities such as maintenance, engineering and services. This immediately introduces a secondary division:- production and non production consumption within this function.

'Building' energy includes warehouses, stores, factory buildings, offices and commercial premises. It usually relates to space heating, lighting, domestic hot water and other equipment such as typewriters.

'Transport' energy is defined as that energy specifically used for that purpose.

This approach provides an easy classification of energy use, into which further more detailed procedures can be fitted. Conservation activities can easily be attached to the structure, hence forming an ideal system for industrial savings. The energy saving check-list (303) was divided in this way. It is also apparent that this segregation can apply to other functions, such as the structuring of energy management (20). Problems may arise, however, with management in the factory being responsible for space heating as well as production energy. Energy managers may, therefore, be considered responsible for one area, within which the three function segregation can still be used.

2.2.1e. The General Procedure

Having provided a classification of energy conservation on the basis of consumption, it is useful to review the methods in a combined form. The diagramatic layout given in fig. 2.2.2 is based on the Lyle approach of primary loss reduction, improved efficiency by reduction of work, and waste recovery and incorporates other activities mentioned in this section. Emphasis is placed on the requirements of management to achieve tighter control over the system. The procedure does of course apply in any of the three cases of building process and transport, and shows how a completely inter-disciplinary system should operate in saving energy.

2.3. General Problem Solving Techniques

Why has energy conservation been slow to penetrate the private industrial sector during the years prior to 1973; why has industry been slow in implementing improvements? Assuming industry has the necessary motivation and incentive to improve the effective use of energy, where then are the wasteful areas and how may they be rectified?

The predominant message is "Identification"; identification of the reasons for negative reaction by management - an implementation deficiency; secondly, which actions to carry out; and lastly where these should be made. As already stated, study of the literature revealed no shortage of suggested action or selection procedure. Concentration must, therefore, be devoted to the first and last items.

"Identity of the problem" is not a topic left undocumented. Commencing with Nadler (136) operational systems can readily be defined in terms of - function, inputs, outputs, sequence, environment, physical catalysts and human agents - which on analysis, determines the associated problems/solutions through comparison of the "ideal" model with the "real" system.

This contrasts with traditional strategy in which the problem is first identified, analysed and broken into components to which models can be fitted and manipulated to provide a solution.

In addition to Systems Analysis, two further approaches to isolating a problem situation include scientific and social disciplines. A possible third combines instinct, skill and a natural feeling for the situation, which cannot be taught but can be developed by constant practice through identifying certain signs.

The social approach consists of little more than useful communication with people. Intimate knowledge of plant and operations may be common to many employees. Contact with such people will yield useful information on problem areas.

The scientific approach, however, relies on analysing the data available. Inter area comparisons consequently highlight the inefficiencies. Unlike the previous examples, however, such a technique requires a rigid procedure.

a. Breakdown of energy into departmental usage, method of usage and energy form.
b. Choosing of the biggest users on the grounds that potentially these are the greatest areas for improvement.
c. Taking of each area, estimating further the percentage improvement likely; multiply up and tackling in order of size.
d. Breaking down to finer detail and choosing of sub-areas.
e. Looking at everything unchanged for a given period.
f. Setting up of standards and performance levels for energy usage relating to dependent factors; i.e., MJ per kg of tyre produced.
g. Recording comparatively and studying of highest/lowest phenomena to see which probable situation poses problems.
h. Recording of improvements and extrapolating results to determine future trends.

Such methods reflect the Pareto approach or value - volume analysis (80-20 Law). Items are ranked and classified on the basis of descending importance or value, so that maximum attention can be paid to the relatively few items which represent the biggest savings (Table 2.3.1.).

The Scientific Method, applicable more to identifying the misuse of energy rather than specifying management problems, requires measurement of physical conditions. Reliability of such data is questionable, a sentiment echoed later in this chapter. Information of this type is not readily available to the industrial category akin to the Fort Dunlop operation.

2.3.1. Alternative Methods

Other methods for estimating the potential for energy conservation and for determining where wastage occurs, can be adapted from Polya's approach (137), and Gregory's procedure (138). The former utilises a treatment of engineering problems using analysis and synthesis derived from classical mathematical origin. Like the work study method, this requires original data.

The second approach, more akin to the Nadler (136) procedure, relies on triggering devices relayed through questioning.

2.3.2. Comment

In most cases, solutions to the energy problem rely on adoption of the above methods in various combinations. For the purposes of discovering the inhibitions towards saving energy, methodology of model derivation in subsequent paragraphs relies heavily on the Nadler approach. In contrast, finding out where actual losses occur requires some measurement and a more scientific procedure; although work study techniques could well provide some answers.

2.4. Energy Analysis and Its Methodology

Energy analysis is a full understanding of the energy input/output relations in sub-systems and total systems, for better restructuring

Table 2.3.1

Usage - Value Classification

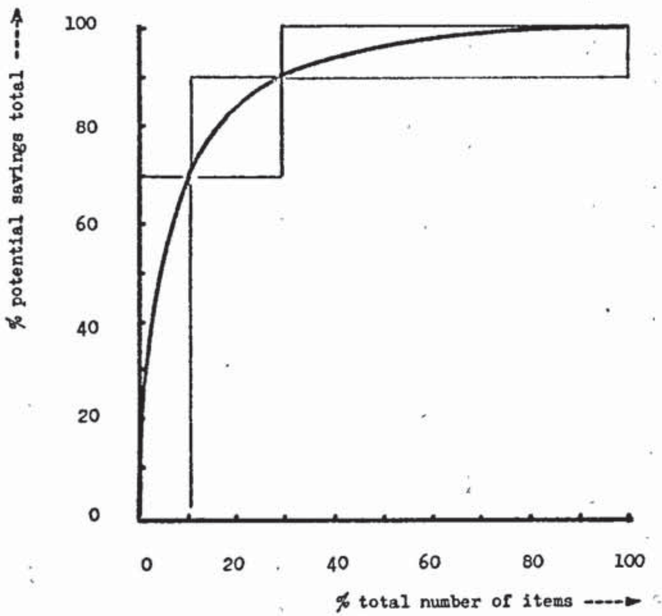
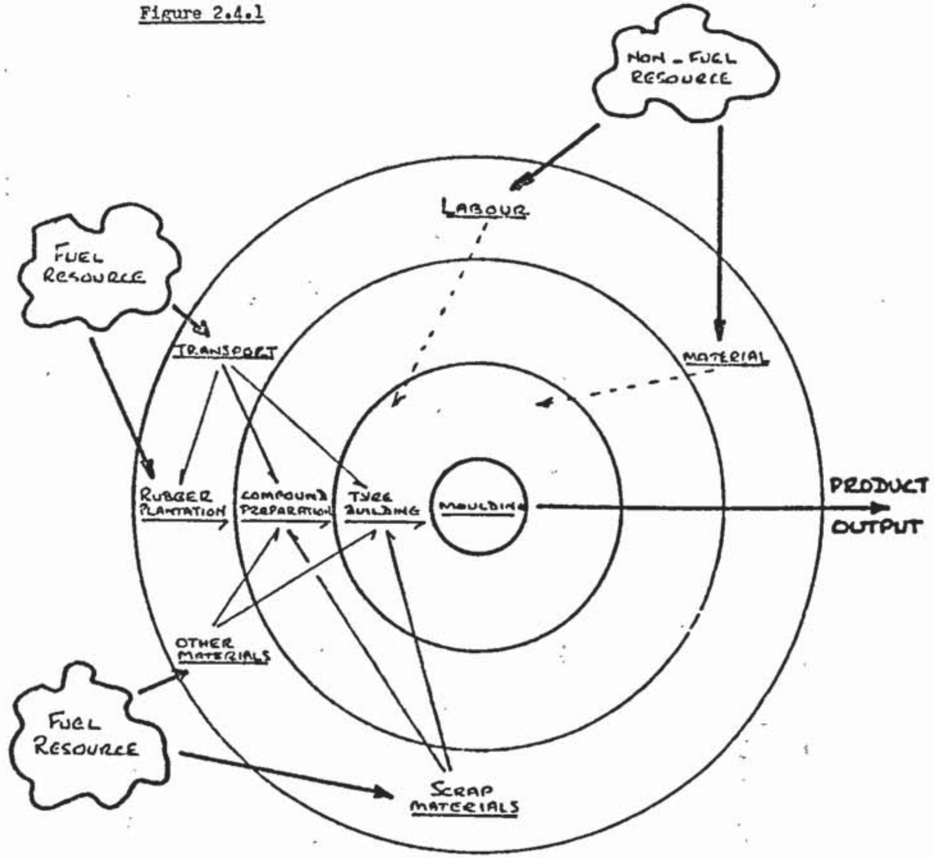


Figure 2.4.1



Economic analysis tends to deal with the transactions across the inner three circles representing the purchases and rates of the producing operation. Energy analysis traces the sequence of the production steps back to the primary resource stocks. Improvements in any one section can therefore be related to other sections and optimal usage determined.

of the systems so that a more thrifty use of energy results. According to P.C. Roberts (140a), energy analysis cannot be compared with work study or value analysis because:

a. energy is a non-substitutional input as opposed to a capital/labour interchange;

b. energy is irrecoverably degraded, whereas physical substance and labour are reproducible.

c. energy use is subject to efficiency limits governed by physical laws.

Whilst these points exert some validity, it would be wrong to assume that either work study had little to offer in identifying energy loss. (See Chapter IV).

F. Roberts (140b) defined energy analysis as:

- "a systematic way of tracing the flows of energy through an industrial system, resulting in the apportioning of a fraction of the primary energy inputs into the system to each of the outputs of that system".

It differs from the heat balance in as much as outside factors play a big part in the equation. The four key aims of energy analysis are (140b).

a. to analyse a process, thus deducing energy efficiency and hence making recommendations for conserving energy;

b. To analyse with a view to forecasting and policy making on a large scale;

c. to analyse consumptions of basic technologies so as to reveal consequences of technology trends or energy shortages;

d. to construct energy costs and examine flows so as to understand the thermodynamics of an industrial system.

Whilst 'b' and 'c' are intrinsically long term objectives, all have relative significance.

2.4.1. Energy Analysis and Economics

In recent publications, Webb and Pearce (139a) refute the viability of Energy Analysis. "Energy analysis and its applications are misplaced since they fail to achieve their stated purposes. Economic analysis already provides a rational base for planning energy use, thus making energy analysis redundant".

Common (139b) considers Webb and Pearce to have been misled by treating energy analysis as a homogeneous activity. He alleges that they have misunderstood its aims and have underestimated its value as a descriptive tool. Moreover, the implications that economics were capable of dealing adequately with problems of resource scarcity and depletion, political interventions and consequential industrial actions, are open to doubt.

Chapman (10 c and d) (139 c) (140c) visualises energy analysis as compatible with economic analysis, although there is an important distinction between the two. Energy analysis is a descriptive method whereas economic analysis is an evaluative method; i.e., the former tells of what will happen should certain choices result and the latter tells which option should be chosen.

Whilst Chapman's thinking relates strongly to the macro systems involving studies of nuclear power feasibility, availability and depletion of fuel resource and the energy costs of materials (139c) (10c) (10d), extension of his theorising to the singular industrial environment demands consideration.

Energy analysis focuses attention on the operation of the total system as well as the subsystem. Economics could only achieve this if market conditions were perfect. With respect to energy costs since 1973, it is obvious that the structure of most markets is grossly imperfect and politically influenced,since most are controlled by monopolies or cartels.

By considering sub-systems in any economy, which in this case may be Dunlop as a company, it is possible to arrive at optimal decision which lead to an overall sub-optimal behaviour of the entire system. Figure 2.4.1., depicts a sequence of operation in tyre making. Provided all stages of production have been included, then the "Gross Energy Requirement" may be computed in the output. Following simple attachment of consequential costs, the optimal investment programme can be decided with respect to changes in sub-systems. Further clarification is given in Chapter VI.

There is an important advantage in examining the operation of a total system as opposed to a sub-system; namely that it enables feedback loops to be identified and analysed.

It is still necessary, however, to develop a procedure for incorporating the results of energy analysis into an economic framework. This is best accomplished by considering the payments for energy separately from those for labour, capital etc., as shown in Figure 2.4.2. This chart shows all the factor inputs for production. The set of production costs can be factored down into a set of individual costs: (10c).

$$c = \sum_i x_i p_i = \sum_j P_j$$

where:

c = cost per unit output

x_i = items purchased

p_i = cost of items

P_j = all individual costs including rent shareholders and labour.

Separating the energy component:

$$c = x_e \cdot p_e + \sum_j P_j$$

where:

x_e = total quantity of energy (i.e., the Gross Energy Requirement of product)

p_e = price of energy

$\sum_j P_j$ = individual costs excluding energy.

'Energy Intensiveness' of a system is defined as the sum of the costs of energy consumption items divided by the value of the commodity of product. (140b).

i.e.
$$I = \frac{x_e \times p_e}{c}$$

Further elaboration of this, given in Section 2.7., exemplifies the effect of intensiveness on adoption of energy conservation.

Figure 2.4.2 Division of factor inputs into payments for fuels (10c)

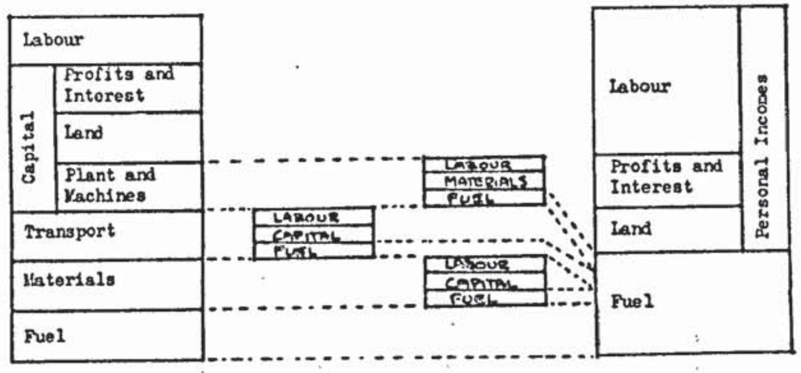


TABLE 2.5.1.

GLOSSARY OF ENERGY DEFINITIONS

a) Gross or Total Energy Requirement (Et)

- the total energy requirement of the system including the energy used in manufacturing the raw materials, plant and equipment, buildings etc., plus the energy expended as direct imports to the system.

b) Net Energy Requirement (Ew)

- the total energy absorbed by the system as direct imports. Note, unlike Et, Ew does not include the energy overhead expended by the energy industries outside the system boundary.

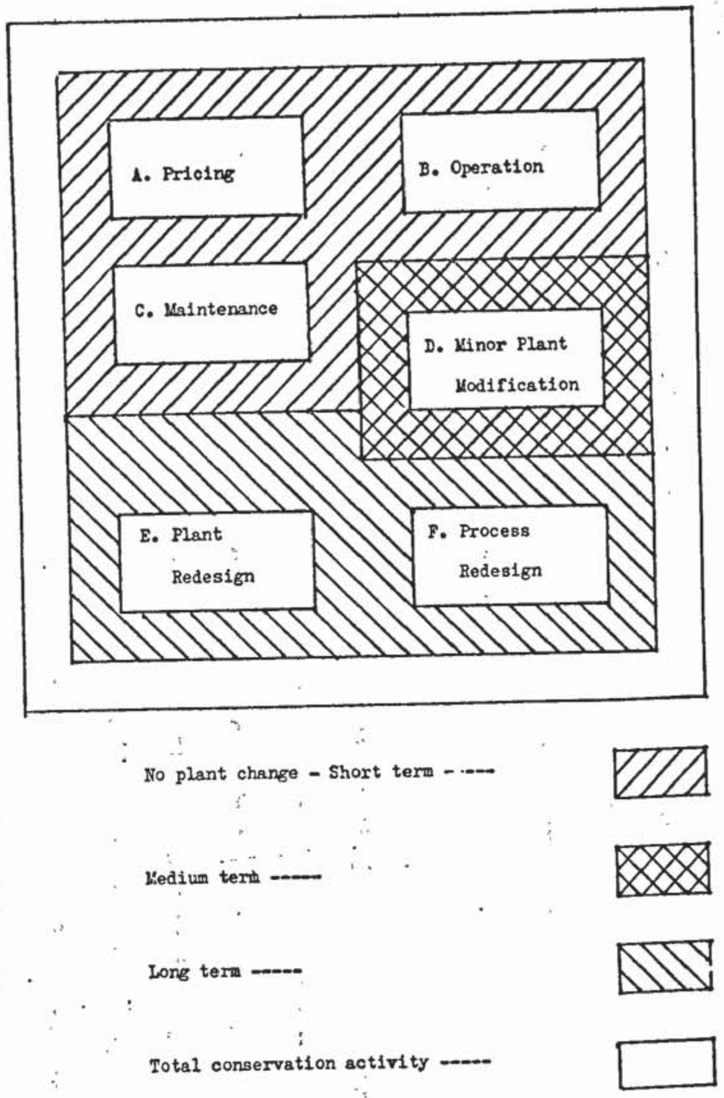
c) Marginal Energy Requirement (Em)

- the variable consumption of the system which may be conveniently associated with a basic unit of measurement i.e., kg. of product produced.

d) Overhead Energy Requirement (Eo)

- the fixed consumption of the system which cannot be conveniently associated with a unit of measurement.

Figure 2.5.2 Classification of energy conservation possibilities



2.4.2. Comment

Energy Analysis allows comparison of different systems having similar functions. This can often be made on the basis of a single number representing the total energy requirement of the system, which makes for easier decisions.

There are many faults with the analytical methods used. Energy analysis can lead to peculiar answers when applied to virtually unknown systems by inexperienced people. Much of the data relies on past, often inaccurate information, thus accentuating invalidity. Even discounting false data, most immediate industrial energy problems relate to operational control or plant failure and not plant and process inefficiency. Clearly better monitoring devices appear to be the requirement for an accurate up-to-date picture of the factory, with systems involving minimal response times.

Often energy is related to other factors such as political or social problems. This involves cost/benefit analysis based on value apportionment of non-quantifiable effects. Data relating to this type of analysis is purely arbitrary.

With respect to long term conservation, energy analysis in the form described has its place. To date, the concept has realised application in forecasting future national energy requirements, evaluating specific energy projects, and deriving energy policies. Little activity has related to sub-systems, such as individual factories outside the macro scale.

Industrialists may well argue that these methods differ little from the simple activities of heat/energy balancing (6) (9) or the use of well established statistical and regression techniques (6) (41) (142). Whilst improvements in approach categorisation and consistency have been forthcoming, it is the author's view that traditional techniques still prevail.

2.5. Classification of Energy Conservation

Energy consumption is analogous to Financial Accounting Terminology:

a. 'fixed' energy - inherent in plant and equipment and in raw materials (Ef).

b. 'Working' or operating energy (Ew)

Total Energy requirement is given by.

$$Ee = Ew + Ef$$

Those and other terms are defined in Table 2.5.1.

The energy requirement for plant and equipment manufacture, raw materials, construction of buildings etc., is usually outside the function of the system and, although relevant to the National economy, can be omitted here. Only after the raw material has undergone some process does the 'net' energy requirement of the material warrant the reduction of scrap and hence energy. Until such time, scrap material reduction has only a monetary value to a company and is independent of energy savings.

Fixed energy could also be excluded on the assumption that energy used during the life cycle of buildings, transport or industrial plant and equipment is often much greater than the energy used in manufacture. (56).

Net energy requirement is attributable to three factors: the process (P), the building (B) and transport (T). So within the confines of the immediate control of any one industry:

$$Ew = f(P,B,T)$$

Each incorporates additional functions such as: plant loading, time, degree of maintenance, attitude of employees, the number of operating steps the ambient temperature, design criteria and so on. In addition, each can be classified in fixed and variable terms. (Table 2.5.1.).

Subdivision of consumptions in this way divides certain facets of energy conservation into categories. For example: Maintenance of steam traps, valves and lagging standards will reduce fixed overhead; whilst new designs in plant and equipment will reduce marginal energy consumption.

2.5.1. Short to Long Term Classification

Extension of this theorising leads to a classification of certain aspects of energy conservation constituting short to long term activities, (Figure 2.5.2.) often based on the "Discounted Cash Flow" rate of return (DCF).

a. Quick savings - usually operation and maintenance improvements involving simple revenue expenditure.
b. Savings effected by modification or addition to existing plant involving some capital expenditure.
c. Savings effected by installation of new plant usually involving considerable capital outlay.
d. Savings which can be made by substitution of the existing process by new processes or techniques.

The time scale involved with each increases with descending order.

Economic classification is specifically meaningful when comparisons are being drawn between industries having different energy intensiveness levels. High technology industries, for example, are traditionally capital intensive and use different approaches to saving than labour intensive companies; more emphasis being placed on plant and process changes (52).

Quick savings resulting from operational changes; good housekeeping, routine maintenance and small expenditure projects are potentially significant in companies having low energy costs. Technological changes result in much larger savings but take longer to appreciate and could be difficult to justify on energy grounds alone. They are often associated with other gains outside the energy spectrum (8).

a. <u>Short Term actions</u> -

These actions produce the greatest returns for effort expended since they can be simple and require little capital expenditure. Being on the wrong tariffs, for example, could cost a company money. Optimum control of energy price is essential. Monitoring of economic and political situations, negotiation of suitable tariffs and predicting future trends requires the induction of the Buying function into energy cost reduction.

Energy which is under the direct control of employees, whether these be production or office workers, offers savings under the next category 'operational' conservation. Such actions do not assume alteration to plant, equipment or process but include switching off lights and machines, turning down the heating etc.

Maintenance of energy systems defines the third category. A function of the factory services facility, maintaining steam traps, insulation covering, leaks etc., should be a continuous activity.

'Housekeeping' has become the collective description for those short term activities. Successful housekeeping relies on:

1. Employee co-operation.
2. Identification of maintenance problems.
3. Monitoring of usage.
4. Good communications.

In factories such as Fort Dunlop, there is little control in purchasing and forecasting, maintenance is severely lacking, and employees fail to appreciate the energy situation. Improved identification and monitoring techniques, better communication through management, enforced motivation and increased employee awareness may, therefore, provide some answers to questions raised in Section 2.3.

b. <u>Medium and Long Term actions</u>

Longer term actions require capital investment. Minor plant changes, such as updating of insulation standards, heat and flash steam recovery, and improvements to condensate return, are part of the engineering function. Implementation of such actions is often restrictive, due to financial limitation and lack of engineering emphasis towards conservation.

Major plant and process redesign, despite the associated capital requirement and engineering effort, surprisingly appears to be progressive. Possibly this is a product of the attractiveness of such projects to scientists, technologists and engineers. In contrast to interests in new investment, the more mundane recalculation of insulation thickness, maintenance etc., reflects little glamour. Major change does have its place, but it is suggested that effective savings can often be produced by greater concentration of the first four categories.

In the past, progress at Fort Dunlop has reflected this. Initial concentration has been towards redesign, at the apparent expense of the simple activities.

2.5.2. The Cost of Energy

Financial incentive is the prime motivator in any operation. Energy costs are a function of:

a. Type of energy
b. Quantity used
c. Tariff chosen
d. Time of consumption

Assuming the energy coming into a factory is an absolute value, then the estimated cost of that energy is given by:

$$C_{est} = \sum_{i=1}^{n} E_i . C_i$$

where E = the quantity of energy

C = average cost of that energy per unit

i = the type of energy - gas, oil, electricity

Note: Due to energy costs being a function of other factors as well as quantity used, the absolute cost of energy cannot be computed without further breakdown. (See Chapter III - Energy Accounting, and Ref. 37).

Should the component costs of a particular energy form increase with time through either a real escalation of the value of that energy or political intervention, the average cost per unit (Ci) will rise producing an amplification of total cost. Such inflation has two over riding effects:

a. the annual energy bill becomes larger.
b. the energy intensiveness of the operation is raised.

Both of these can stimulate conservation activity in the ways previously described. Alteration to any of these functions, could beneficially counter the increases; for example:

a. Substitution of one energy form for another (8).
b. Reduction of the consumption component.
c. Alteration of operating procedures i.e., making use of cheaper electricity on night shift working.

The degree to which any change takes place will depend on the magnitude of the increased price and the importance of energy in the component costs of production.

Primarily large, rapid energy price increases make previously unattractive conservation projects financially viable. Measurement of feasibility is usually based on a payback time or a discounted cash flow return. The minimum return acceptable will depend on the financial state and policy of the company.

It is believed however, that in view of the rapid escalation of fuel prices since 1973, a rate above that of general inflation, decisions relying on DCF return for evaluation are both misleading and incorrect. This identifies yet another incomprehensible barrier to implementing actions in an otherwise declining economy.

It is argued that DCF methods provide a basis for comparison between energy projects and other capital requirements. Whilst it is not advocated that energy project feasibility be divorced from other considerations, it is believed that based on DCF returns alone, decisions are being obscured from the true costs and benefits.

Component costs of production influence management attitude. Increased energy intensiveness, therefore, will tend to arouse greater interest in conservation.

As demonstrated in a later section of this chapter, the majority of industrial organisations have only a small part of their operating costs attributable to energy. This emphasises a second major reason why companies have been slow to recognise the potential of energy savings. In such cases, attitude change has to be achieved by alternative methods. Publicity and training may be a partial solution.

Although important, market forces may not be the only impulses which will produce changes in a system, subsequent sections attempt to show how these and other factors influence the status of energy.

2.6 A Model of Energy Conservation in Industry

The problems associated with energy saving have now been highlighted. At this stage in the research it was deemed necessary to hypothesise the reasons for any deficiency. Then followed the ideal model approach, where the mechanism of change and subsequent resistances were identified. Commencing with the traditional concept of the 'black box' ideology, Appendix G examines four conceptual models developing this theme.

Returning to the government's conservation strategy, since 1973 the overriding factor has been price increase. This can be viewed as an 'impulse' entering a company's boundary upon which management may be expected to instigate some counteraction proposals. If nothing happens, the attitude within the company may be said to be negative. In reality this consequence was upheld, probably for reasons which include the passing on of increased costs to final consumers, negative attitudes, and lack of awareness of the need to save. Resultant government action reinforced this belief through the introduction of publicity and information services (19) (20) on how to save and energy management structuring. Further examination led to postulation of the total effects on an impulse and the development of an 'Hydraulic' analogy.

Behavioural patterns can be represented by a model in which new and existing technology, implementation, and final results can be viewed as hydraulic flows; impulses, feasibilities and incentives being considered as pressures. 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 actions. Inefficient and static management makes no provision for continuity of maintenance or new idea, thus effectively stemming the flow. With respect to energy, Fort Dunlop echoes these hypotheses.

The rate at which conservation potential is converted into results is subject to time factors. A third 'Flush' model describes the speed at which a proposal reaches fruition in terms of positive forces and negative resistances to implementation. Analogy can be drawn with electrical theory.

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 the decision making process. A final model was, therefore, conceived taking into account the energy intensiveness of the operation and the annual turnover value of the company. Fort Dunlop exhibits an intermediate intensiveness with a high turnover, which points towards relative success in conservation. For reasons identified in the previous models and under 'Other Factors', however, this is not the case.

As a consequence of all the modeling activities, it was apparent that the restricted acceptance of conservation were due to two main reasons:

a. the type of industry into which Fort Dunlop operations fell;

b. the inherent inadequacies within the factory boundary.

Subsequent sections examine these concepts, resulting in a clear definition of the problems facing energy conservation within this category of British industry.

2.7. Energy Classification of British Industry

Industrial activities can be segregated into a number of different classes. A classification of British industry can be obtained from either the Standard Industrial Classification Department of Trade and Industry (123); the Input - Output Tables for the UK, 1968 (124); or the Census of Production, 1978 (36).

Input/output tables (124) give an analysis of 'direct' and 'indirect' energy usage for product requirements. The drawbacks of this method are many, but it is useful in estimating energy costs of industrial production, the energy intensity of capital goods, and the energy 'profit' for energy industries.

Inputs and outputs may similarly be derived from statistical sources such as the national Census of production (36). The aggregation of statistics for a given industry will provide an average energy requirement for a unit of output.

There exists, however, the potential for segregating industry into categories of energy usage, which could highlight some of the difficulties associated with conservation. Table 2.7.1., depicts some of the more obvious possibilities.

For the purpose of industrial classification, three methods are predominent:

a. Energy intensiveness

TABLE 2.7.1.

POSSIBLE MEANS FOR CLASSIFYING ENERGY

1. Usage
   - Type used (Gas or electricity etc.)
   - Purpose of use (lighting, heating etc.)
   - Location of use
   - Quantity used
   - Specific usage

2. Physical function (Process, Building, Transport)

3. Operation function (Production, Non-production, etc.)

4. Financial
   - Absolute Cost
   - Intensiveness

5. Classification of company operation activity

   (Continuous or batch process, capital intensiveness etc.)

TABLE 2.7.2.

ENERGY INTENSIVENESS AND ABSOLUTE VALUES FOR A SELECTION OF BRITISH INDUSTRY

	1973 % Intensiveness	1968 abs. Value £1000
1. Cement	23.75	27802
2. Fertilizers	18.84	13302
3. Iron and Steel (Not cast iron)	14.26	203887
4. Stone, slate, chalk, sand etc.	10.37	3131
5. Paper and board manufacture	10.31	22956
6. Cans and metal boxes	9.04	821
7. Man-made fibres	7.00	11066
8. Sugar	7.81	4474
9. Paint	7.64	1836
10. Bricks, fireclay, refractories	6.96	16522
11. Aluminium and aluminium alloys *	6.48	11524
12. Rubber goods	5.68	10983
13. Motor vehicles	5.37	32230
14. Cocoa, chocolate and sugar confectionary	4.57	4646
15. Grain milling and breakfast cereals	4.75	4621
16. Non-ferrous metals (except aluminium)	4.73	7962
17. Electrical machinery	4.20	7367
18. Textile machinery	3.89	2076
19. Tobacco	3.76	1732
20. Footwear	3.16	1653

(* known to be an underestimate).

Statistics obtained from Input/Output Tables (124) and updated by NEDO (1) provide intensiveness data. Values of absolute net energy cost from Census of Production 1968.

b. Absolute energy costs

c. Classification by company operation activity.

Based on these, it may be possible to relate to levels of conservation activity.

2.7.1. <u>Energy Intensiveness in Classification</u>

The level of energy intensiveness, will tend to dictate the day to day emphasis on energy in operation and hence the degree of control and effective level of conservation activity. Companies having a higher intensiveness will direct greater emphasis to saving energy than say labour. Table 2.7.2., gives examples of energy intensiveness in British Industry.

Energy intensiveness, however, relates to both direct and indirect primary input. The figures in Table 2.7.2., therefore, include the energy content of raw materials imported by the industry. This explains the apparent high values for fertilizers and man made fibres.

The data in Table 2.7.2. can, at best, only provide indication of importance of energy, since values relating to "net energy usage" cannot be realised. Severe departure from this hierarchical listing however, is unlikely. Cement and Iron and Steel industries are energy intensive, whilst tobacco and footwear are not. Rubber goods and Dunlop lie somewhere inbetween.

Energy conservation is believed to receive greater attention in the Cement and Iron and Steel industries; with the level of awareness to save decreasing with hierarchy. When the track records are considered (8) this is generally found to be the case.

Since 1973, energy intensiveness has increased in most industries. Great emphasis of energy conservation should therefore, result at all levels. Why then has this not happened in Dunlop?

Taking the rubber goods industry as an example, despite intermediate intensity, better performance might have been anticipated. The intensity could of course be influenced by the contents of synthetic in preference to natural rubber thus inflating the real portion of net energy cost and positioning the industry at too high a level of hierarchy. Alternatively, intensiveness is not the only indicator. The conclusion must be that there are other influencing factors.

2.7.2. Classification by Absolute Energy Cost

The Iron and Steel industry in 1973 accounted for over 23% of the total industrial consumption. Their energy costs, are therefore, far in excess of other consumers. This factor adds further emphasis to energy saving.

Absolute cost of total net energy employed by a company will have bearing on success of energy saving. Table 2.7.2., outlines the 1968 costs for the selected industries. Increases in both intensiveness and absolute cost since 1968 have, however, been extensive (1). Management is, therefore, very much aware of the total cost of energy to the company.

The Rubber Industry ranks twelfth amongst those industries shown. The track record, however, fails to reflect the anticipated level of effective energy use. Whilst these factors have some bearing on conservation, therefore, other more influential controls must exist; for example, management may fail to maintain enthusiasm long after the initial impact of price rises.

2.7.3. Classification by Company Operation Activities

It has been assumed, perhaps without sufficient evidence, that it is the big spenders on energy and the more energy intensive industries which will contribute most to the development of energy saving methods, and who, under conditions of greatly increased energy costs, will make the major savings in national terms (121). In the face of alternative methods of cost reduction, these industries stand to achieve greatest benefit through energy saving and have made it their business to know all the facts.

Large energy users are of two distinct classes (121). The first type consists of industries, such as Iron and Steel, Cement, etc., where process energy cost clearly forms a substantial part of the total cost of the product. Within such operations energy usage is often concentrated, clearly defined and conservation technology well advanced. Above all, due to the significance of cost, energy savings register early consideration in decision making.

In a subsidiary class within this category are the high technology operations. These constitute the Fertilizer, Chemical process and Petroleum industries. Here the process is continuous and energy intensive, but differs from the above through greater diversity and less concentrated usage. High level of capital investment and technical sophistication, in such organisations, have placed great emphasis on energy saving and integrated usage.

Large consumers which express neither of these characteristics constitute the second class. Such industries include Motor Vehicle and Rubber manufacture. Here the energy component of product cost

Figure 2.7.3

Classification by Company Operation Activity

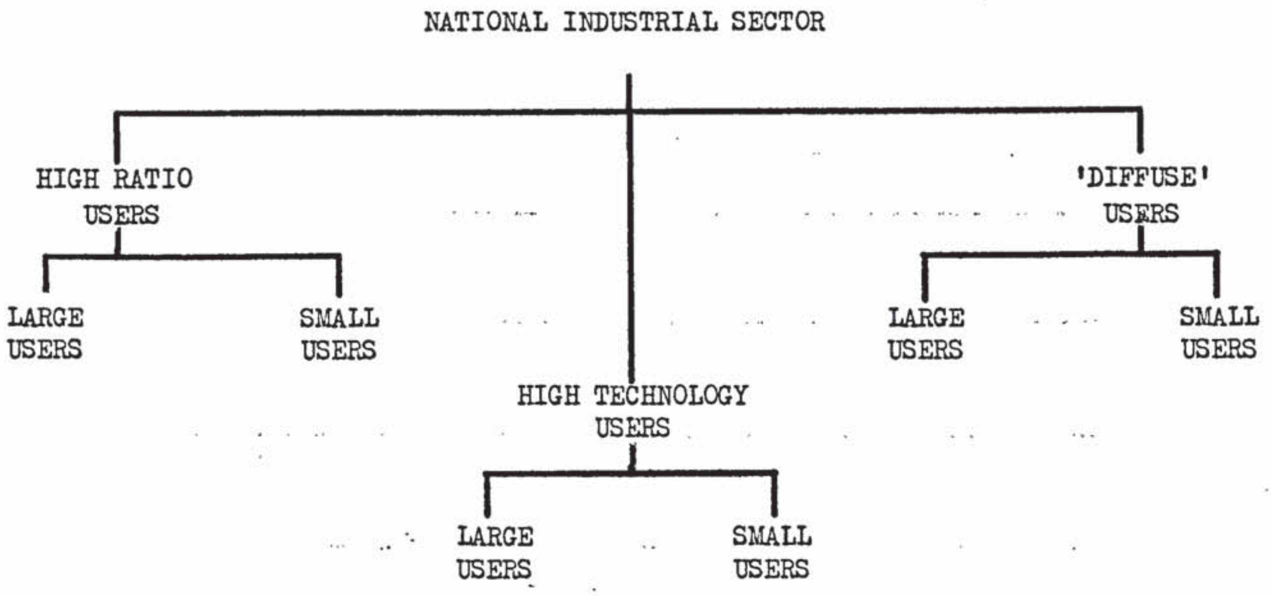


Figure 2.7.4 Energy Conservation Activity Matrix For The National Industrial Sector

Industrial Sector	Energy Usage Level	Capital Intensive: New Process	Capital Intensive: New Plant	Capital Intensive: Process Modification	Capital Intensive: Plant Modification	Capital Intensive: Maintenance	Capital Intensive: Building Changes	Non-Capital Intensive: Accounting	Non-Capital Intensive: Optimum Operation	Non-Capital Intensive: Control	Non-Capital Intensive: Attitude Changes	Non-Capital Intensive: Audits	Non-Capital Intensive: Forecasts
HIGH RATIO USERS	LARGE	X	X	X	X	X	X	X	X	X		X	X
	SMALL			X	X	X	X		X	X		X	
HIGH TECHNOLOGY USERS	LARGE	X	X	X	X	X	X	X	X	X		X	X
	SMALL				X	X	X		X	X		X	X
'DIFFUSE' USERS	LARGE				X	X	X	X	X				
	SMALL					X	X						

X - Denotes some energy conservation activity.

is low. Intrinsically this has led to poor efficiency. In addition, energy is used in a variety of forms spread through a diverse network in small quantities. Responsibility for conservation is poorly defined, control of consumption is inadequate due to wide dispersion of use, and potential improvements severely lacking. Industries having these characteristics are defined as "Diffuse Users". Dunlop tyre operations fall into this category. (Figure 2.7.3).

2.7.4. Conservation in 'Diffuse' Industries

Prior to 1973, lower costs and intensiveness levels are believed to have contributed greatly to the inefficient use of energy in diffuse industries. Priorities were directed towards material and labour cost reduction. Since then the picture has changed throwing emphasis on energy conservation, but due to the diversity of use, lack of control and other problems, implementation action has been slow. Figure 2.7.4., depicts a matrix of energy activity priorities in specified industries.

The small savings so far obtained by diffuse users have resulted from adoption of ideas generated by the class one consumers. It is questionable whether this is a suitable approach. Attitudes towards energy, ease of identification, rate of implementation, etc, are markedly dissimilar. Clearly an independent approach is needed.

2.8. Summary of the problems identified

The model theorising exercises have produced some answers as to Dunlop's failure to make sufficient impact with energy conservation. Whilst cost increases provide some incentive they alone fail to motivate management or other company employees. Despite improved incentives, however, the level of activity remains disappointing. The problems as seen were therefore defined as follows:

a. Awareness - Due to past practices, attitudes of both management and other employees are poor. Reasons include lack of awareness of costs, how to save etc. Improvements were essential in deriving a solid basis for savings. Introduction of Publicity and Training were thought to be possible solutions.

b. Motivation and Incentive - Financial constraints and poor engineering emphasis have limited medium or long term improvements and maintenance levels. Major changes are not, however, the only line of attack; good housekeeping for example offers significant contribution. Lack of improvements could be held to poor management and employee attitude. Motivators and incentives needed investigation.

c. Communications - Communication has contributed to poor response and implementation times. Formal communication both inside and outside factory boundaries has failed to emphasise costs or losses or to provide the necessary information on how to save. Improvement in the communication structure and the attitude of receivers was necessary.

d. Organisation - All companies require energy management. Control, identification of losses, implementation of actions, accounting, analysis and buying of energy were believed to be inadequate. Clearly separate organisational functions need to be defined.

e. Implementation - The standard of maintenance and effective implementation of new projects was poor. Implementation of actions needed to be brought under good management control.

f. Identification - Singularly the worst problem facing conservation, identification of losses and wasted energy in a diffuse system such as Fort Dunlop left much to be desired. Energy analysis methods, accounting and monitoring functions were obviously inadequate. Without knowledge of where losses were occurring, performance efficiency etc., it was impractical to suggest any action. Identification, therefore, formed a prime requisite.

CHAPTER III

SAVING ENERGY - THE NON - TECHNICAL APPROACH

3.1 Chapter Preview

It is believed that human participation, good communication through effective energy management, and the employment of energy purchasing and accounting functions reflect greatly the success of conservation campaigns.

The belief that energy conservation techniques were well established before any energy crisis, and that the lack of success in resultant savings in the industrial sector has been a consequence of alternative factors, demands the inclusion of discussion on non-technical measures. Through empirical modelling and theorising, Chapter II hypothesised intrinsic difficulties facing effective conservation, which included:

a. limited employee awareness, at all levels, of the need to save;

b. poor employee attitudes, at all levels, towards energy and conservation;

c. lack of incentive to reduce wastage;

d. poor communication

e. ineffective energy management and control

Implementation of actions are as much a function of these as technical knowhow and availability of other resources. Scope for improvement is needed in many industries including Dunlop. This chapter discusses possible ways of rectifying the difficulties, most of which reflect the potential of good communication and positive management. Due to the nature and enormity of the subject, identification of losses and resultant actions are excluded. Adequate consideration is provided in subsequent chapters.

3.2 Introduction

Ideas, fostered in certain quarters, that all energy conservation problems would be solved by concentrating on the simple engineering, production and technical aspects of improving thermodynamic and utilisation efficiencies are a complete fallacy and are delusions that deflect effort from the real target; namely that everyone must learn to use energy much more intelligently. Like road safety and hygiene, energy usage is a personal matter which everyone must learn from school children upwards, in the hope that it will place Britain in a better position for future years. (26). Clearly, since in the more labour intensive industrial climates energy usage is significantly related to employee density (Chapter 5), initial success of all campaigns will depend on the awareness and understanding of energy matters by these people. Personnel, not conscious of energy waste as they are of other kinds of waste, may react vigorously at the sight of scrap products or squandered finances, but view steam leaks with equanimity. (97) Publicity, training and alternative incentives to enhance awareness and knowhow must, therefore, be worthwhile.

The UK national campaign - "Energy sense is common sense. Save It" -, described in Chapter I, had by 1977 been in evidence for three years, saving the country a reputed sum over the period in excess of £1000m. It is difficult to assess the extent of success attributable to publicity and training alone since economic recession, price rises, weather conditions and political pressures will have all made significant contribution. Measurement is easiest in the Domestic sector, where such actions as insulation improvements have been outstanding (26).

Acceptance by industry of the Department of Energy publications has been disappointing (30). For a total of 1252 sites visited by the Energy Thrift Scheme and representing a cross-section of British industry, 35% made use of posters, 26% - booklets, 19% - general advertising and 51% - used nothing at all. Although the United Kingdom has been accredited with the implementation of a very strong and effective public information campaign, more intense than other OECD countries, it is believed that this has had little effect in the private industrial sector. (7)

3.3 Communication

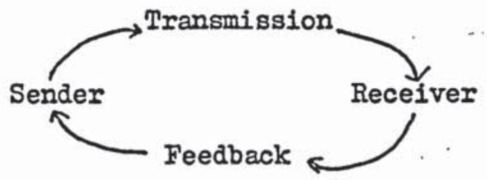
"Knowledge is of two kinds. We know a subject ourselves, or we know where we can find information upon it" - Dr. Samual Johnson; April 1775.

Successful imparting of information and knowledge requires effective communication.

A simple communication model shows how an ideal system should operate.

Figure 3.3.1.

Communications Model



Success depends on one of three factors:

a. information being comprehensible and of interest

b. effectiveness of formal communication channels

c. the willingness of the receiver to react and provide feedback

Johnson's quotation intimates an active receiver, who if interested in energy or conservation will either act on inherent knowledge or will enquire as to what can or might be done. The receiver's attitude can be said to be positive. In British Industry, for the major part, receivers tend to be passive. Unless motivated through some incentive, even the most effective communication channels and interesting information will fail to bring response. When attempting to include employees in day to day energy saving, therefore, the first step is to create an active receiver environment. In the domestic environment, conservation ideas are well received since market forces have created a susceptive attitude.

Assuming the receiver is both receptive and actively willing to provide feedback, the success of the system will now rely on the communication channels being effective. Often problems of channel capacity, length and discontinuity inhibit progress. Management, through itself and its operation, provides the ideal vehicle for good channelling. Conservation, therefore, requires 'Energy Management'. Under such organisation, information on wastage and suggested improvements can be collected. Similarly cost information, the need to save, and the necessary knowhow can be transmitted.

Finally, the information imparted by the sender must be relevant, comprehendible and interesting. At Fort Dunlop, much of the energy information distributed is complex and incomprehensible. The receiver is mostly overloaded with irrelevant facts. Selective information transmission is the key.

Communication in energy conservation are, therefore, of ultimate importance. The remaining sections of this chapter emphasise: the need for careful consideration of how, what and where to communicate. Much is to be gained by using the well established marketing techniques in designing and setting up such a campaign.

3.4 Management and Organisation

Lyle (6) advocated the basis of energy management principles as far back as 1947. Companies, he said, could benefit from appointment of a specialist body of people to investigate energy consumption and savings in required areas. These could either be under permanent employment or alternatively, external consultants, should economic justification be impossible.

In subsequent years, suggestions as to who should be appointed the "Energy Manager" have varied from the Chairman of the Company, to the Works Director, the Chief Engineer, the Plant Engineer (143) and the Foreman (39). More recent years have seen the initiation of energy committees incorporating management, trade unions, engineers etc. Appointments have differed from those of a temporary nature, to additions to existing responsibilities, and instatement of a specific post. Conditions and requirements, however, vary from factory to factory. It is, therefore, necessary to review the functions and possible organisational structures of energy management before commitment to any one system.

3.4.1 Functions of Energy Management

In the present climate, Senior Management must increasingly concern themselves with energy.

- "No organisation can expect to maintain its position if it fails to ensure security of future energy supply and strict control of its utilisation" (4). In agreement with government directive (20), top management should demonstrate a firm commitment to and a positive lead on energy conservation so that, through an organised structure, resources can be allocated within every company achieving efficient and economic usage, thus eliminating undue waste.

- "Every board of directors should urgently consider appointing an 'Energy Manager', someone of sufficient standing with:

a. direct and specific responsibility for the wise and careful use of energy

b. the role of co-ordinating the work of each production function or plant operation, including office and transport management.

TABLE 3.4.1

Functions of Energy Management (4)(20)

1. To motivate management and employees.

2. To create awareness and influence employee attitudes; this includes management & shop floor.

3. To provide effective communication channels and contact with the necessary personnel and to impart only meaningful and useful information.

4. To control and rectify the monitoring, accounting, budgeting and reporting of usage, costs and efficiency.

5. To identify inefficiency, losses and possible savings through audits, measurements and other analyses.

6. To evaluate and recommend conservation projects, both short and long term, at the same time controlling their implementation - A priority listing of project feasibility is recommended.

7. To provide adequate maintenance and affect good housekeeping.

8. To make provision for communication of new ideas and technology both external and within the company.

9. To liase with other factories and existing working groups within the company.

10. To consolidate an energy policy as to purchases, stocks, usage, conservation and available finance for present and future operation.

11. To maintain sufficient technical know-how within the organisation and to initiate research and development or obtain external advice where necessary.

12. To compile a basic manual or handbook outlining the code of practice for the company.

13. To maintain awareness of world and national energy developments and to advise senior management.

14. To generally co-ordinate communicate and control energy matters in the company, due consideration being given to emphasise achievements both internally and externally.

c. the responsibility to stimulate possible energy-saving investment" (20).

These indicate but a few of the possible functions. In accordance with the findings from the previous chapter, a list of essential qualities and activities is given in Table 3.4.1. In essence, good energy management requires adequate communication, assignment of specific responsibility, backing from Senior Managers and consequential co-operation of departmental management. Reflecting the 'Hydraulic Analogy', this means opening the valves as wide as possible to allow maximum implementation of conservation actions.

3.4.2 Possible Organisation Structures

Ideas as to who should be the Energy Manager or what organisational structure should exist are as varied as the number of factories operating in the U.K. No single system is best for all situations. Requirements of small firms will differ from large organisations. It is not the intention of this section to recommend a system, structure or appointment, but to offer alternatives.

The options open to industry include the following possibilities, which may be considered for individual selection or in a variety of combinations.

a. the appointment of a single person;
b. creation of a department;
c. creation of a section within a department;
d. formation of committees or working parties;
e. setting up of a corporate management or advisory service;

f. simple allocation of responsibility to an existing job;

g. appointment of external consultants;

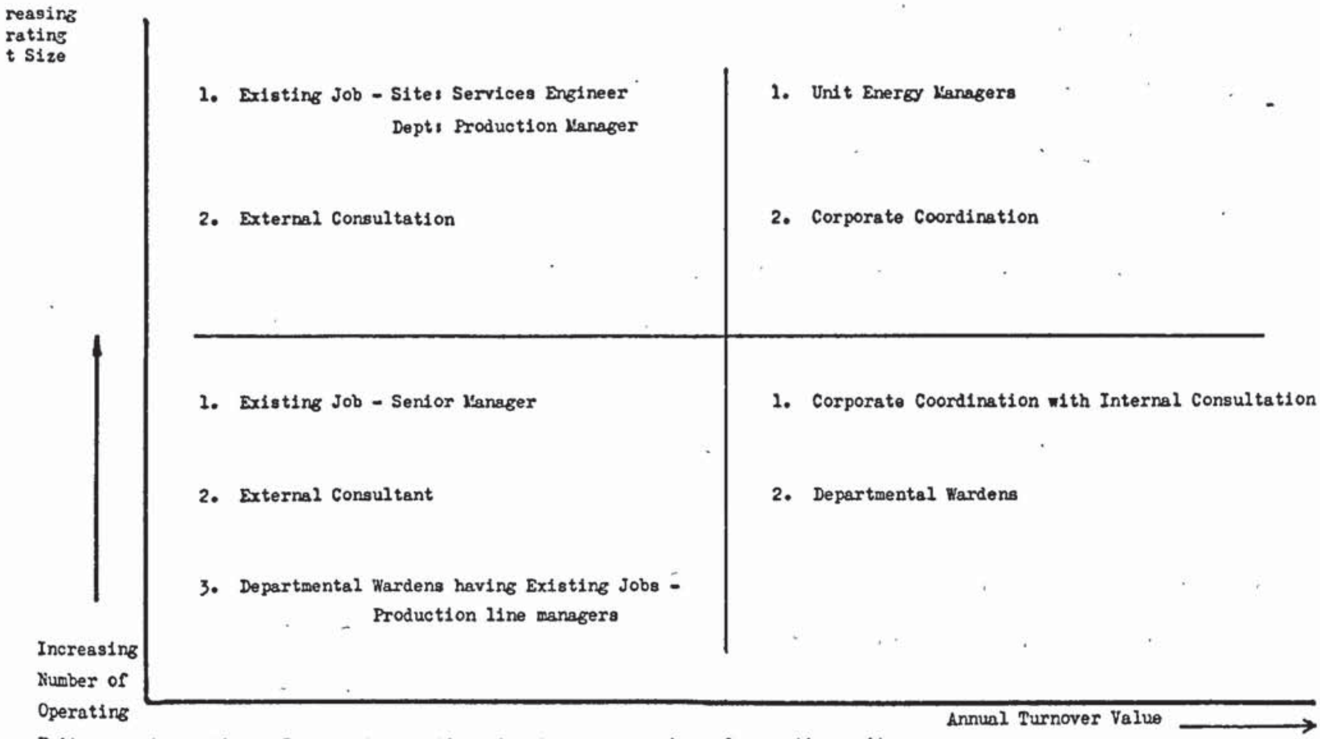
Choice will be governed by factors reflecting the policy, thinking, type of operation and financial position of the company. It is possible to formulate graphical models of management alternatives based on these factors (Figures 3.4.2 and 3.4.3).

Energy usage is a function of all personnel employed within the company, since all use the resource in one form or another and exert a degree of control. Companies must, therefore, look to all individuals for effective management of energy. Encouragement, communication and co-ordination are the keys.

Whilst it is imperative that all efforts receive individual undivided support, it is not the board's function to co-ordinate energy. Cases have been reported (144) where company chairmen of large firms have taken on the responsibility of managing energy. Feasibility of such actions is in doubt. The closer energy management is to the point of usage, the more effective will be the savings.

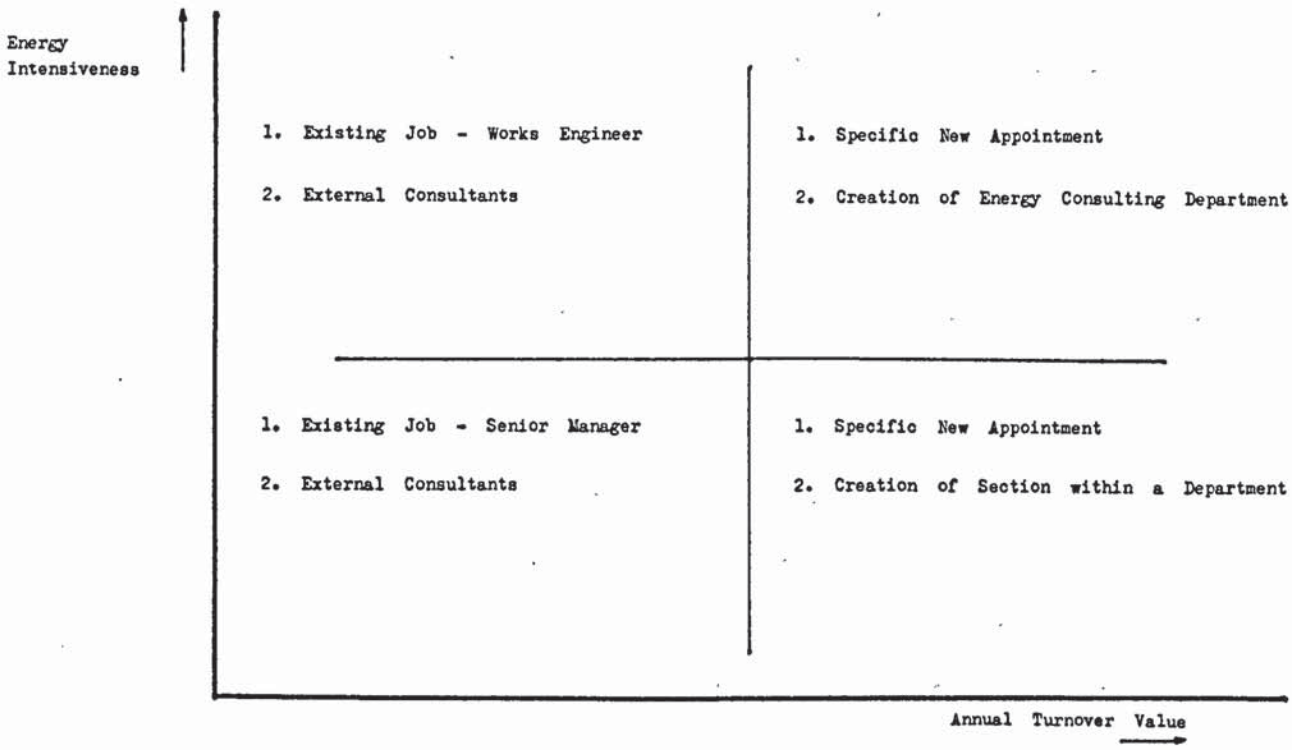
Detailed work (i.e. actions, improvements, monitoring etc.) is not a job for senior managers (4). Line managers and supervisors should have clear direction on their responsibilities within their own departments; overall co-ordination and direction being vested in the appointed energy manager. In small organisations, these duties may be only part of his overall job, or he may simply be the man nominated to liaise with a consultant. This thinking agrees with the government suggestions (20).

Figure 3.4.2 Operation Level - Company Size Model



Assumption - Increased operating size decreases number of operating units.

Figure 3.4.3 Intensiveness - Company Size Model.



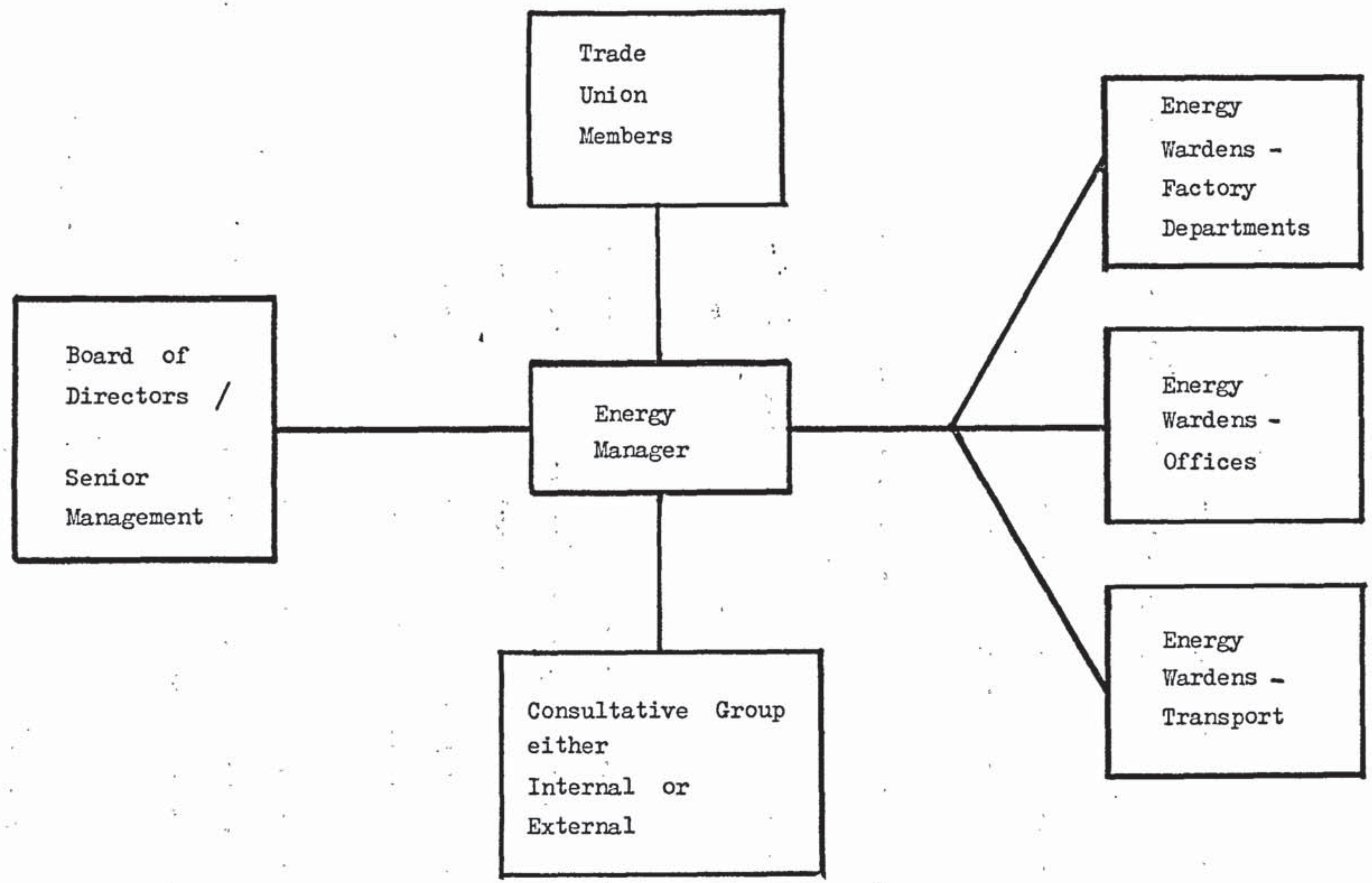
In large organisations, the energy manager should be a qualified fuel technologist or engineer, with experience of costing methods and the financial evaluation of capital projects, and with the ability to command support from colleagues. It is essential to clarify his terms of reference, emphasis being given to direct control of the resources necessary to achieve actions rather than appointment in an advisory capacity. In addition the energy manager should report direct to a senior executive and enjoy access to all pertinent information (4).

Appointment of a specialist consultative group, either drawn from the company's own expertise or from external sources may be considered as an alternative or addition. Smaller companies will tend towards the latter due to financial limitation. Technical guidance is essential, and this may have to be 'brought in'.

With the co-operation of trade union members through representatives, energy conservation programmes can realise the potential more rapidly. Involvement of unions is, therefore, a primary requirement (20) (144). Beliefs that management should be able to control without union consent are old fashioned and shortsighted.

A suggested structure for Fort Dunlop is shown in Figure 3.4.4. For successful savings, co-operation, co-ordination and communication are stressed. In consequence, it is not recommended that centralised or corporate management be attempted. Contrary to the beliefs of Johns - Manville corporation (35), control of energy usage cannot be affected from a remote or centralised location. Knowledge of the plant and operation is a prime

Figure 3.4.4 Energy Management Communication Diagram.



requisite. In very large organisations, justification of a corporate, advisory and monitoring service may be possible provided direct dictation to individual operating units is avoided.

3.4.3 Dunlop and Energy Management

Energy management at Fort Dunlop fails on four accounts; (See Chapter I for details of the structure).

a. Whilst concern over energy is expressed by the Dunlop Board, there is still little commitment and backing at factory level.

b. Engineers are well aware of the exceptionally poor use of energy, but, despite regular reports, departmental production management fails to react to declining efficiency. This could also be a product of poor communication and incentive.

c. The energy and fuel engineers have no direct control over maintenance, housekeeping, new projects etc. With one of the major problems being implementation, and whilst their position is purely advisory , success will be restricted. Improvement in communication with senior and line managers is required.

d. Non-realisation of appointment of Departmental Energy Wardens and regular subsequent meetings with energy management, form breakdown in the communication chain.

Amongst other things, there is substantial statistical evidence to enforce these claims. Savings have not been forthcoming. When compared with Fort Dunlop, the successes in smaller factories has been much greater. It is suspected that organisational structure and closer contact with the shop-floor could provide the reason. In fairness, however, it should be stressed that Fort Dunlop is an old factory, with peculiar ways derived from the type of operation and physical size. The true effect of engaging an Energy and Fuel Engineer may not as yet have been felt.

3.4.4 Comment

To quote J.J. O'Connor (33) - "Energy management calls for getting the most from every mega - joule of raw fuel and every kilowatt hour of electrical energy. It requires good housekeeping, maintenance and improvements in plant, equipment and process operation. These are hardly new ideas, but rather well-proven values of a most practical nature, and yet often glossed over. Taken a step further, the concept of energy management, when applied across a company's prime interest areas, will result in a practical step, with present day tools and knowhow, towards realistically meeting todays needs and laying a sound basis for tomorrows industrial and social growth".

In the end, it is the energy manager, acting in a co-ordinating and liaising capacity, who, with the support of senior management and with the backing of the trade union membership, will achieve these goals.

3.5 Purchasing Functions

The advent of continual sharp rises in energy price and the continuing variation in competitiveness between fuel types, demands better control of energy purchases in any industrial organisation. Substitution of one energy form for another (natural gas for coal) has singularly provided substantial savings in both energy, through higher efficiency, and costs; the latter being predominant. (See Chapter I). Without decrying the success, this saving resulted from a need to replace old plant and not from forward energy planning. Whilst it is easy to criticise with hindsight, it should still be pointed out that, had a little more thought been given to forecasts of energy trends, the savings might well have been larger if, for example, a fixed gas contract had been negotiated for a longer period.

No one can gaze into a crystal ball and effectively forecast 'Energy Crises'. Political influence, such as that expressed in 1973, is a hazard industry has to face. It is, however, possible to monitor progress and development trends based on sound scientific, technological and factual criteria. Availability of resources, for example, must partially reflect the market value of a specific energy source. The advent of North Sea gas and oil, produced in relative abundance, bears some influence on decisions regarding policy and actions. Availability of large quantities of coal must be reflected in future investment programmes. There is, therefore, incentive for a company to keep its finger on the pulse of the 'Energy Economy'.

3.5.1 The Function of Purchasing

Purchasing is a specific responsibility within a company. In small firms it might only form part of an individual job specification; larger companies have their own Purchasing or Buying Departments. Buying energy is an important aspect of any system's operation and must, therefore, be designated significant importance to become the responsibility of an individual employee whose function it is to:

a. Ensure that there is an adequate supply of suitable energy sources for operations within the company.

b. Purchase that energy at the minimum possible price; (Note, it is not advocated that activities contravene company policy through actions involving speculation or dishonesty)

c. Ensure that prices charged by monopolies are within acceptable guidelines and, where necessary, exerting objection. Larger companies hold greater command in this respect. Involvement of centralised advisary bodies, institutions and associations can add emphasis.

d. Negotiate annual contracts, due regard being given to price trends and fuel supplies. If flexibility of choice of energy source is available, i.e. through multi-fuel steam raising facility, selection should reflect comparative prices. This will act as a useful bargaining tool.

e. Effectively scrutinise, update and provide correct selection of tariff. Tariffs often change, leaving many organisations to pay a disadvantagous price.

f. Monitor, record and forecast trends related to the company, region, national and world environments.

g. Maintain awareness of political, social, economical and environmental changes; including technological and commercial advancement. It should be possible to predict several alternatives which could result from potential actions. This would partially nullify effects of sudden change.

h. Control and check all invoicing and bill-payment with respect to price, measured consumption etc.

Due to the complexity of the buying function, it is not recommended that the Energy Manager or Engineer be responsible for purchases unless company size restrictions prove otherwise. Instead, a Senior Buyer should be given the task of securing adequate sources, with added directive to communicate regularly with senior management, accountants, engineering and energy management. Clear policies and directives should also be formulated. Use might well be made of consultants when viewing the energy charges. Such organisations have the necessary knowledge of tariffs, through regular contact with both the energy industries and the final consumers, to optimise energy prices. In recent years, Fort Dunlop has made use of such aid.

3.5.2 Tariffs

The development of present day structures of charges for electricity and gas go back to the times of their first being supplied for the purpose of sale to the public and industrial/commercial organisations. The 'Electric Lighting Act' of 1882 marks the beginning for electricity; legislation and charges for gas precede this still further.

a. Electricity

Whilst tariffs are now less complex, a simple charge structure applicable to all users cannot be evolved. The supply of power to industry is a complex matter. The load - consuming capacity of a single plant may be quite enormous and because of shift patterns, strikes, seasonal and weather variation, meeting the demand at all times is a matter of much technical difficulty. In consequence, a wide variety of tariffs exist, varying according to the categories of users and, to a small extent, the geographical situation.

Tariffs for industrial and commercial users are based on a number of elements (3):

- the actual units used (and for some users the time of day or night)
- the installed electricity consuming capacity
- the maximum demand;
- the power factor of the user's installation

The choice of the best tariff is not easily made. The provision of detailed, accurate historical records of load and use are required. Advice must generally be sought from a specialist; nearly always the Area Boards are the obvious first choice.

b. <u>Gas, Oil and Coal</u>

Approximately 60% of all gas used goes to Industry and Commerce, where most supply agreements are based on 'one off' tariffs reflecting the rate of consumption and the consistency of supply. For example, cheaper tariffs for 'interruptable' and minimum supply contracts may be possible. There are usually no alternative gas tariffs on which to base comparisons. Price levels rely entirely on negotiation each year, which must reflect the price paid for alternative energy forms. The importance of sufficient knowledge of prices and trends cannot be over stressed.

Like gas, oil and coal contracts are individually negotiated. These, however, will differ in as much as both rely on road or rail transport, introducing distance and location into the tariff by means of delivery charges. Price, however, in the case of oil, is independent of direct government control and hence the monopoly of the nationalised industries. This provides an excellent bargaining position for discussions on gas and coal contracts.

3.5.3 Energy Prices, Trents and Forecasts

The purchasing function cannot be included as an energy conservation measure but must be associated with energy cost saving. Since both eventually reflect a financial result, inclusion is justified in a conservation programme and hence in this thesis.

Assuming the most beneficial tariffs have been negotiated and accepted, the second part of the buying function is to ensure that the monitored consumption and appertaining functions agree with the invoices received. Each should be justified through company cost accounting records. One problem which may arise here is the discrepancy of timing of meter readings;ie. coincidence of factory reading times with those of the energy supply industries.

The energy buyer must also monitor price trends within the company and throughout the country. Wherever possible, comparisons with other factories should be made. Such records should culminate in the formulation of some degree of forecasting. This is of particular importance with respect to energy substitution with new plant, negotiation of contracts, and selection of fuel choice for day to day operation in multi-fuel systems. The importance of communication with engineers and plant operators in the power plant and boiler house must be stressed.

Fluctuation of oil prices for Fort Dunlop have in the past year fallen below those for gas. "Minimum take" levels for gas, negotiated in the tariff, has limited beneficial use of oil to a small rate. With the advent of North Sea Oil, the reversal of rapid oil price increases could reasonably be forecast. The negotiated gas contract should, therefore, reflect such predictions, allowing use to be made of the cheaper oil.

Political consequence cannot of cause be forecast. Regular regard for the national and world situation, should, however, be exercised. With three of the four energy supply industries under nationalised control, political intervention in pricing could have large consequence independent of real market levels.

It is the buyer's function to emphasise the need to optimise energy use for production purposes. With particular reference to electrical tariffs, use can be made of the cheap rate periods, avoiding times of maximum demand etc. To date, communication between Buying, Production and Engineering Departments leaves much to be desired.

3.5.4. Concluding Comment

A significant part of the total cost of energy is its actual purchased net cost. Energy is usually treated as other materials, requirements being specified by Engineering or Production

TABLE 3.5.1

Areas of Investigation for Energy Purchasing (4)

1. Changing to a fuel or grade in more plentiful supply

2. Providing a more uniform offtake

3. Accepting larger deliveries

4. Accepting off-peak or seasonal deliveries

5. Providing improved delivery facilities - speeding up delivery procedures and reducing demurrage

6. Negotiating interruptable supply arrangement

7. Changing to a more advantageous tariff

Departments, and purchased by a specialist department at the best terms which can be negotiated. In practice, mains gas and electricity are often supplied on fixed tariffs with, at first sight, little scope for negotiation. Oil, LPG and sometimes solid fuels, are more usually bought on a competitive market. In agreement with G.A. Payne (4), there is no 'best buy' as far as energy is concerned. A continuing audit of fuel and energy purchases will enable prices to be compared on a common basis, but every form of energy has particular advantages and disadvantages requiring the opinion of the user. Once broad requirements have been communicated, scutiny of tariffs and price scales may reveal opportunities to lower costs. Table 3.5.1. itemises some areas for investigation.

The buyer should periodically consider the real value of his business to various suppliers, considering their problems with seasonal demand fluctuation, transport, labour, competition, cash flow and availability of supply. He should seek to make his business more attractive to them in return for cash advantage. In other words, the buyer should know a supplier's most pressing problems and weaknesses as well as long term trends in availability and price.

The buying function must provide a meaningful contribution to energy cost savings and should be including in senior management strategies.

3.6 Accounting Function

"Information on existing energy purchasing, distribution and use is essential before any improvements or future planning can be seriously contemplated". (G.A. Payne (4)). The forms of data collection will vary, but certain features will be common to all organisations. The accounting function is linked strongly with energy audits and analyses. The purpose is to establish the basic relative costs of various energy forms, the main consumptions, and the principle points at which there is waste or inefficiency. Records, should reflect performance through regular reports.

In accordance with government thinking (20), accounts should record the form of energy and total consumption (expressed in the most convenient units); total production associated with total energy consumption, specific energy consumption associated with specific production, output or performance; and prices together with associated costs. Cost and management accounts may well already provide much of this basic information and should, therefore, be brought under energy management control.

It is not the intention of this thesis to give detailed account of the cost accounting procedures of Fort Dunlop or the Tyre Division. Methods of approach differ from one accounts department to another. For energy, formal publications by O. and P. Lyle (6) (145) provide adequate information on the subject. The basic procedure and objectives are laid down in Chapter II. Whilst there is criticism of the existing system, it should be remembered that the information processed by the accounts is only as accurate as the data input from the engineers. The subject of metering and its problems is extensively covered in the next chapter.

3.6.1 Accounting for Energy

The objective of an energy accounting system is to provide adequate records of energy costs, consumptions, and efficiencies for individual departments or the entire factory, so that greater control of operations will produce optimum efficiency. Such published information has two main functions:

a. to identify inefficiencies and wastage for day to day operations,
b. to provide a record of performance and trends for long term appraisal.

A further objective of energy accounting is to present this useful information, through some comprehendable form, for quick and easy appraisal by all employees and managers.

Overall general figures can be very misleading. (4). Variations in production output may result in variations in specific energy consumption (6)(145) (See Chapter 5). A greatly improved performance in a department may balance a deterioration elsewhere.

Energy records are often best collected by individual departments and related to their own output. In this way improvements and lapses can be detected more quickly. Data collected on a routine basis must not, however, be examined in a casual manner. They must be considered carefully by a competent person, who is aware of all the implications and who is able to make the correct interpretations.

Process energy consumption and non-factory energy consumption have significant differences. On large sites such as Fort Dunlop, many group and company activities, such as research, marketing and technical operations, are consolidated on the site in addition to the manufacturing function. These must be kept apart from the process energy figures and charged separately. This procedure has since been adopted at Fort Dunlop.

It is also necessary to separate that energy used directly for process from that for space heating. If accounting records aim to provide control, this segregation is necessary.

The effective usage of energy in one production department will vary from another unless the product is the same in each and manufactured by the same process,having identical steps and environmental conditions. Comparisons can, therefore, be difficult. Departmental performance can of course be compared with its own past trends and budget.

Fort Dunlop Works Accounts amass meter readings of the main energy flows and production levels. Mostly based on apportionment,this data, once processed by the computer, undergoes a subdivision, into cost centres within individual departments. These cost centres incorporate major plant items,either as individual entities or collective assemblies. Most major production departments have individual metering but some apportionment is still necessary. A summary of the data issued is given in Table 3.6.1.

Apportionment is a necessary evil. Whilst the engineer might enjoy reliable, continuous measurement of every energy user down the line, it is obvious from the arguments given in Chapter 4 that this is often both uneconomical and inaccurate. It is

Table 3.6.1

Costs and Consumption Data Included in Fort Dunlop Energy Accounts

			Units
Water	Town / Borewell / Circulating	Site Consumption	1000 gals.
		Production / Non- production Consumption	1000 gals.
		Effective Usage - Production	gals./kg.
		Purchasing / Pumping Costs	£/1000 gals.
Gas / Oil	Steam Raising / Other Usage	Site Consumption	Therms
		Boiler House Consumption	Therms
		Other Consumption	Therms
		Purchases / Handling Costs	£/Therm
Electricity	-	Site Consumption	1000 kWh.
		Maximum Demand	kVA.
		Prod. / Non-prod. Consumption	1000 kWh.
		Effective Usage - Production	kWh./kg.
		Purchases / Handling Costs	£/kWh.
Production Output		-	1000 kg.
Compressed Air	-	Site Consumption	1000 cu.ft.
		Prod. / Non-prod. Consumption	1000 cu.ft.
		Effective Usage - Production	cu.ft./kg.
		Primary Energy Consumed	kWh.
		Primary Energy per 1000 cu.ft.	kWh./1000 cu.ft.
		Cost of Production	£/1000 cu.ft.
Hydraulics	-	Effective Usage	gals./kg.
		Cost of Production	£/1000 gals.
Steam	-	Site Consumption	1000 kgs.
		Process / Heating Consumption	1000 kgs.
		Primary Energy Consumed	Therms
		Water Consumed	1000 gals.
		Condensate Returned	%
		Specific Energy Consumption	Therms/1000 kgs.
		Specific Water Consumption	gals./1000 kgs.
		Boiler House Efficiency	%
		Effective Usage - Production	kg./kg.
		Purchases Costs	£/Therm
		Total Production Cost	£/1000kgs.

fitting, therefore, that engineers decide first which flows should be metered and second how and at what value the apportionments should relate. In themselves, however, apportionments do not measure efficiency. Performance can only be determined by actual measurement.

A second, but different, stage of apportionment arises when the sum of individual 'down stream" meters fail to total the main reading, or readings become unavailable through strikes by readers or inaccurate through obvious mistakes. Consequently, through predetermined programming, the computer will insert a budget or average figure in place of the actual reading. Alternatively, the computer divides the difference between the main and the sum of secondary readings amongst the relevant cost centres. Accountants postulate that some figures are better than none. Whilst this might be true for accountants or even managers, such data are of little use to the Energy Engineer. The error reports from the computer must be viewed regularly and the necessary action taken to inform managers, engineers and the instrument personnel.

Apportionments also exhibit another major problem. The original criteria upon which they were based are often obsolete. Due to efficiency variation in machines, varying load factors, or even changes in distribution of energy through the removal of plant and equipment, figures are totally unrepresentative. The accounting system should be kept up to date, apportionments being continually reviewed. Regular communication should be maintained between engineers and Works Accounts. At Fort Dunlop, there is strong evidence that this is not so. It is recommended that an investigation be made of the services network and metering to verify accounting data.

Information of any kind must be consistent. At Fort Dunlop there is an apparent discrepancy between departmental energy figures issued by the Works Accounts and those provided and used by some engineers. This is thought to be due to differences in calculation procedure and inclusion of conflicting production output data. Further investigation is required.

3.6.2 Energy Costs

"Energy Costing" forms a significant portion of energy accounting activities. Due to the real time delay between the need to produce information for managers and the advent of the bill receipt, it is necessary to estimate the price of the energy form. Actual variation is small unless adverse conditions prevail (excessive maximum demand increasing the unit price of electricity). All apportionments, expected prices and budgets are annually predetermined in the Fort Dunlop Plan. Alterations to this plan are of course possible.

As expected, the price per energy unit increases with sequential conversion processes (i.e. gas to steam to HPHW). Labour, material and overhead charges account for this. These costs are reflected in the reports published.

Energy Costs and their method of accounting can often produce misleading results. An example is reflected in the complexity of the pricing superstructure for electrical energy purchases. Fort Dunlop adopts the basic principle of charging for electrical usage on the basis that electricity pricing has one component;

this being the summation of unit (p/kwh) plus associated KVA and other charges divided by the actual consumption. Such a situation fails to show reasons for increased electrical cost since there is no facility to distinguish between, say, increased maximum demand charge and actual units consumed.

Whilst this has less importance in the eyes of the engineer, whose job it is to study actual consumption as well as costs, to the Production Manager segregation could be more beneficial since it is the overall cost which will be studied. Moulder (37), advocates division of energy costs into sources and subdivision of each source into its use. It is not possible to reduce all cost centres to this level but it is recommended that departmental data move towards basic principles.

3.6.3 Reports, Records and Presentation

Table 3.6.1. adequately describes the type of information presently distributed in the Fort Dunlop system. Since the age of computers, it appears common practice to overwhelm management with a sophisticated degree of information. Requirements for data will depend on the receiver. One problem facing energy conservation is the failure of employees to react to information on energy performance. Method of presentation could provide the solution.

Communication to all employees of costs, usage and efficiency forms an important part of any publicity campaign. Accounts Departments should be in a position to supply such information, in a suitable form, for presentation on notice boards and in press releases. Presentation might include use of graphs, pi - charts or histograms.

Departmental and site statistics on effective energy usage are already in evidence in graphical form. As indicated in Chapter 5, however, accurate interpretation of information is not always possible. Efficiency at present is measured on the premise of production output. This is believed to be totally unacceptable. For example, no account is taken of ambient temperature variation or, more profoundly, the influence of energy overheads. It is suggested, therefore, that effects of variations in production output be normalised,and influence of weather conditions be accounted for in measuring efficiency. A model, which takes account of these factors, is described in Chapter 5.

Regular reports form an important part of energy control. Information conveyed should not be unduly complex but should reflect the salient points in a comprehendable form. Fort Dunlop, through weekly, monthly and annual computer print-outs, regurgitates reams of information for production and engineering management. Amongst these, energy data tend to be swamped by general cost centre apportionments, making appreciation of trends difficult. This has resulted in the weekly issue of a more simplified account of services, costs and usage. For quick assessment of energy efficiency, a simple one page document now incorporates the effective usage, consumption, price and total cost of each energy source and conversion process. Due to effect various influential factors on trends and efficiencies, however, it is recommended that these reports be issued monthly and not weekly.

Reports provide a useful tool to management control. To make maximum use of information of this kind, the minimum delay from measurement to the issued report is required. Fort Dunlop Works Accounts operate a minimum turnround of one week. Additional engineering reports take two or three weeks. Losses or wastage could take a month to detect, resulting in obvious financial disadvantage. Automatic monitoring with daily printout would solve this problem.

The accounting function provides a useful measurement of performance after the event, but alternative means must be sought to detect present inefficiencies.

Records of past performance at Fort Dunlop have been readily available, albeit that the format of the reports and the degree of information has changed. For engineering purposes, accurate records in consistent format are essential.

3.6.4 Budgets & Targets

Use of predetermined budgets for management control are common to most Dunlop accounting systems. All too often, however, in practice; a budgetary figure is selected on the basis of production target output, and by predetermined ratios based on likely variables at each production stage. Quite apart from the inaccuracy of the ratios etc., budgetary control does not easily separate the energy costs that would have been incurred had target outputs been achieved from the actual costs relative to actual output. Management Accountants would point out that variance analysis achieves this. However, the arguements put forward in Chapter 5 enforce belief that variation in actual energy figures can be caused by factors other than wastage and losses. As postulated by M. Moulder (37), budgetary control is not a suitable vehicle for conveying control information on energy usage to management, even if the budget splits up energy usage by function costs such as space heating. It is suggested that the models shown in Chapter 5 hold hope for greater control of energy.

As indicated in Chapter 1, Fort Dunlop operates an energy target system. Annual targets, based on inclusion of predicted improvements, tend to conflict with budgets. Two sets of figures only lead to confusion. It is proposed that, should budgets be used, the energy conservation aspect be included at the time of the Budget Plan, and targets abolished. This enforces the need for communication between the Energy Engineer/Manager and Works Accounts.

3.6.5 Comment

The word 'control' to the author implies three separate strategies:

a. the collection of data sufficiently disaggregated, accurately measured and collated for the purposes for which it is intended;
b. the assembling of the data into cost classifications based on groups of costs behaving in a like manner, assigned in a given functional area, or by a particular process;
c. converting the previously collated and assembled data into a format suitable to facilitate managerial control, and the information actually presented to the appropriate level of management, suitably indicating areas needing further enquiry.

No system can be worthwhile if its sophisticated superstructure is founded on inadequate or misleading data; or if the processed information is clouded by major inferences other than energy wastage. New energy accounting procedures must evolve along with improved measurement and reporting if control at Fort Dunlop is to improve.

3.7 Employee Participation

Contrary to common belief in industry, every employee of a company uses or makes use of energy whilst in the working environment. In consequence, therefore, all amployees, whether these be machine operators, secretaries, cleaners or senior managers, have some control over how energy is consumed in the immediate vicinity of their environment or area of responsibility.

As identified in Chapter II, however, lack of awareness of types of wastage, need to conserve energy and possible actions is a major problem. This is often a consequence of poor attitude and inadequate communication. Conservation action plans must, therefore, include positive steps towards improvement.

5.7.1 Publicity and Training

The Department of Energy UK 'Save it' campaign has been in evidence since January 1975. Although questioned by R. Dafter in a Financial Times survey (26), reputed savings associated with publicity have since that time been in excess of £1000m for the domestic sector. Unfortunately the same proportional improvement cannot be associated with industry.

The basic aims of energy publicity efforts, utilised the simple 'squealer - do it yourself' philosophy (121). Without extensive publicity, it was hoped that by feeding cost information to employees some positive reaction would result. Once an employee had identified a potential loss, it would then be easy to provide him/her with a 'do it yourself' set of actions. Such was the initial attempt to get employees involved. In reality, this failed for the following reasons -

a. employees had little sense of duty to save energy;
b. whilst domestic costs were relevant, company costs carried little importance amongst employees;
c. cost information alone was inadequate;
d. there was no incentive for employees to save energy.

These factors pointed to the general poor attitude to energy within Fort Dunlop and the inadequacy of campaigns, such as the 'Save it', to produce desired results. Clearly a carefully designed programme was required; one which would identify the target areas, clarify the objectives and communicate the appropriate information. In other words it was necessary to produce a campaign, which encompassed the four basic aims previously mentioned and which could be identified with the company.

A. <u>Fort Dunlop Energy Attitude Survey</u>

Throughout the last week in March, 1975, staff of the Market and Economic Research Department, U.K.T.D. carried out a survey on the Fort Dunlop site into employees attitudes to saving energy in their homes and at work (122). The survey was instigated by the Chief

Engineer, U.K.T.D. and was conducted with the approval of the unions represented on the site. In all some 283 employees co-operated in answering the questionaire at the factory gates, in the social club and canteens. The results obtained were as follows:-

a. The National TV and press campaign achieved a high level of recall (74%), three quarters of whom thought it was worthwhile and along with price rises must influence decisions.

b. A small percentage (7%), from the anti-advertising segment of public opinion, opposed the national campaign, condemming its cost and lack of effectiveness.

c. It was clear that in reaction to more expensive energy, high proportions of Dunlop people had taken practical steps to limit consumption in a number of areas. These people would thus be open to persuasion that if energy savings make sense at home it makes sense at work.

d. A high percentage believed that steam, electricity and water savings were possible in their place of work; electric lights and idle-running machinery being commonly emphasised due to those being most visible. Only a small percentage expressed concern for better use of machinery by more effective labour deployment and re-cycling of waste.

Although the survey presented useful information, covering the basic objectives it failed to indicate employees' attitudes to energy and conservation (86) (129). Attitudes are not just beliefs, they also involve emotional and behavioural patterns.

B. Publicity in Dunlop

Emphasis in the U.K. Tyre Division centred initially on saving energy through improved design, maintenance and production techniques (94). By 1975, however, it was realised that employee motivation at all levels was critically important for success. Following the social attitude survey (122) a campaign was initiated in January 1976.

Within a month of the launch in the 'Dunlop Drum' (130), interest and impetus waned; training schemes, internal public relations or the suggestion scheme all remaining theoretical ideas. The reasons for lack of success were:

a. inadequate design and planning of campaign, this being attempted with engineering bias and no marketing skills.

b. limited preparation and co-ordination.

c. limited impact at launch.

d. no continuity.

In consequence, a second campaign was commissioned, organised and controlled by the author. With due consideration to previous experiences, the following criteria were laid down, many of which were emphasised in the first attempt but not implemented.

a. to establish a co-ordinated, inter-disciplinary approach to the design involving marketing, production, engineering, press, training and industrial relations functions.

b. to maintain continuity for at least two years.

c. to include both internal and external public relations exercises.

d. to establish communication channels with management and unions.

e. to initiate an energy savings suggestion scheme and suitable competitions; rewards being non-monetary and preferably energy related.

f. to ensure sufficient impact at launch.

g. to encompass the entire Dunlop U.K. operation and to identify as potential targets all employees from senior management to the shop floor employees.

h. to repeat the attitude survey so as to measure success and to monitor actual progress through monthly data reports.

i. to maintain an umbrella of general publicity materials with specific emphasis on high consumption areas.

The basic objectives were:

a. to create awareness of the types of energy loss, general cost data and the need to save.

b. to provide knowhow on simple conservation and housekeeping techniques, for both the domestic and industrial environment, and to outline past and future developments.

c. to maintain awareness throughout time.

The design of this campaign differed little from the Government 'Save It' programme but added a further dimension to energy saving by identifying conservation with particular Dunlop factories. It was important to utilise the success of the domestic campaign by relating these savings to industrial situations and by maintaining a link with the already well established government initiative.

C. The 'Mr Save It' Package

Commencing with a brief (328) outlining the objectives, proposed procedures, media and target groups laid down under the Dunlop Advertising Manual - Code of Practice (104), detailed information on energy usage at Fort Dunlop and throughout the U.K. Tyre Division was prepared (329). This included information on consumption and costs relating to inefficient usage, factory layout, labour distribution, plant and equipment, and improvements already attained. Adhering to the criteria and objectives laid down in the previous section and to the principles of marketing and advertising design, the basic package was produced. The timing of the launch was to coincide with the 1976 Autumn altering of the clocks. The actual launch, to some disadvantage, took place in March 1977. Details of the programme are given in Tables 3.7.1 and 3.7.2.

It was essential to maintain a continuity factor throughout the campaign. A 'Mr Save It' personality was created (See Plate 3.7.A). It was believed that such a creation would permit freedom of speech on any aspect of energy conservation and usage without recrimination from management or unions. Posters and stickers also required regular review, fresh design and constant replacement.

Few employees at Fort Dunlop understood the meaning of megajoules, therms or kilowatt - hours. All tables relating the losses, together

Proposed Procedures for the Operation of the Mr 'Save It' Campaign

The following table outlines the progression of the campaign as executed at Fort Dunlop. Although many of the items are applicable to other Dunlop factories, it will be necessary to select and adapt these to suit specific situations.

Pre – Launch

1. Carry out an attitude survey on employee attitudes to energy. (Mostly it can be assumed that improvement in awareness and attitudes are desirable and that publicity is necessary).
2. Set up communication channels with management and unions, short presentations on the proposed programme being given to each.
3. Install departmental 'Energy Notice Boards' near exits or clocking – off points
4. Ensure the availability of suitable analysis and accounting methods to provide information on any improvements or statistics.

Launch and Operation

5. Launching of the campaign should be at a suitable time (i.e. changing of clocks before winter) and in a way to give greatest impact. Full use should be made of the internal press announcing the event and timed to coincide with the first of the posters. A public figure or celebrity may be considered for the opening.
6. Continual use of factory newspapers etc. should highlight specific points on savings, success stories etc. in both the factory and the home. Links between the two environments are essential.
7. Poster hanging should be sequential and carried out by an appointed employee. This avoids the problems of placing them in the most suitable place and at a specific time. The following sites are recommended:
   - Near exits and doors
   - In corridors and at the end of passages.
   - Near specific plant and equipment.
   - Near clocking-out points.
   - At the factory gate.
8. Posters should be in sufficient numbers to create an impact and should not be left up for too long a period. Old posters should be taken down when new ones go up. Due consideration of the timetable (Table 3.7.2). is required to avoid these becoming part of the furniture. (Each Fort Dunlop issue numbered 600 posters for the 250 acre site housing the employees).
9. Stickers should act as reminders to employees. They should be placed near appliances and switches by appointed personnel. Smaller stickers can be stuck on internal correspondence, reports, overalls, lapels etc. – these are easily distributed to departments.
10. Regular monitoring and reporting of successes and other statistics in the internal press and on energy notice boards is required. Such information should be in a form readily understandable and having sufficient impact. (Bar and pi-diagrams). Additional attitude surveys may be beneficial.
11. Part of the existing suggestion scheme should be bent towards energy. Separate schemes are not recommended since energy often accounts for only part of the saving. Rewards should not be monetary but might include weekend trips to the continent, roof insulation etc. Donation of prizes should be bi-annual, assuming suggested savings are beneficial, and must be accompanied by full press coverage.
12. The public address system can be used. Messages should not be of special events, since only part of the site may be covered, but need to be varied, general comments, limited in number and include information on success as well as publicity. Care must be taken not to overload the listener.
13. Internal phone calls By divisional directors to departmental management are useful. These should be simple enquiries into apparent inefficiencies and convey congratulations on improvements. Apparent interest at senior levels will motivate shop floor management. Phone calls need only be occasional and of random selection.
14. Visits by union representatives, foremen, managers and other selected employees to Energy Industries will increase interest. This must be accompanied by publicity.
15. 'Save It' stationery including memos, internal envelopes and pay packets may provide reminders.
16. Consumption statistics should be painted on all machinery, plant and equipment.
17. Special overalls or badges could be issued to energy maintenance teams. This will identify the campaign with employees but may present difficulties with unions and the people asked to wear them.
18. 'Executive' desk models of Mr 'Save It' may be presented to successful departmental managers.
19. Competitions, both inter-departmental and inter-factory could provide an incentive for collective saving. It may, however, be difficult to find a common basis for effiency estimation in tyre plants.
20. Departmental improvements should not go unrecognised but should be accompanied by reward.
21. Energy saving campaigns and successful savings should be published in the local and national press but only when there is some significant advance.
22. Large posters advertising 'Dunlop Saves Energy' can be placed at factory gates and in prominant positions.

Table 3.7.2

DUNLOP MR. 'SAVE IT' PUBLICITY CAMPAIGN - TIMETABLE OF OPERATIONS

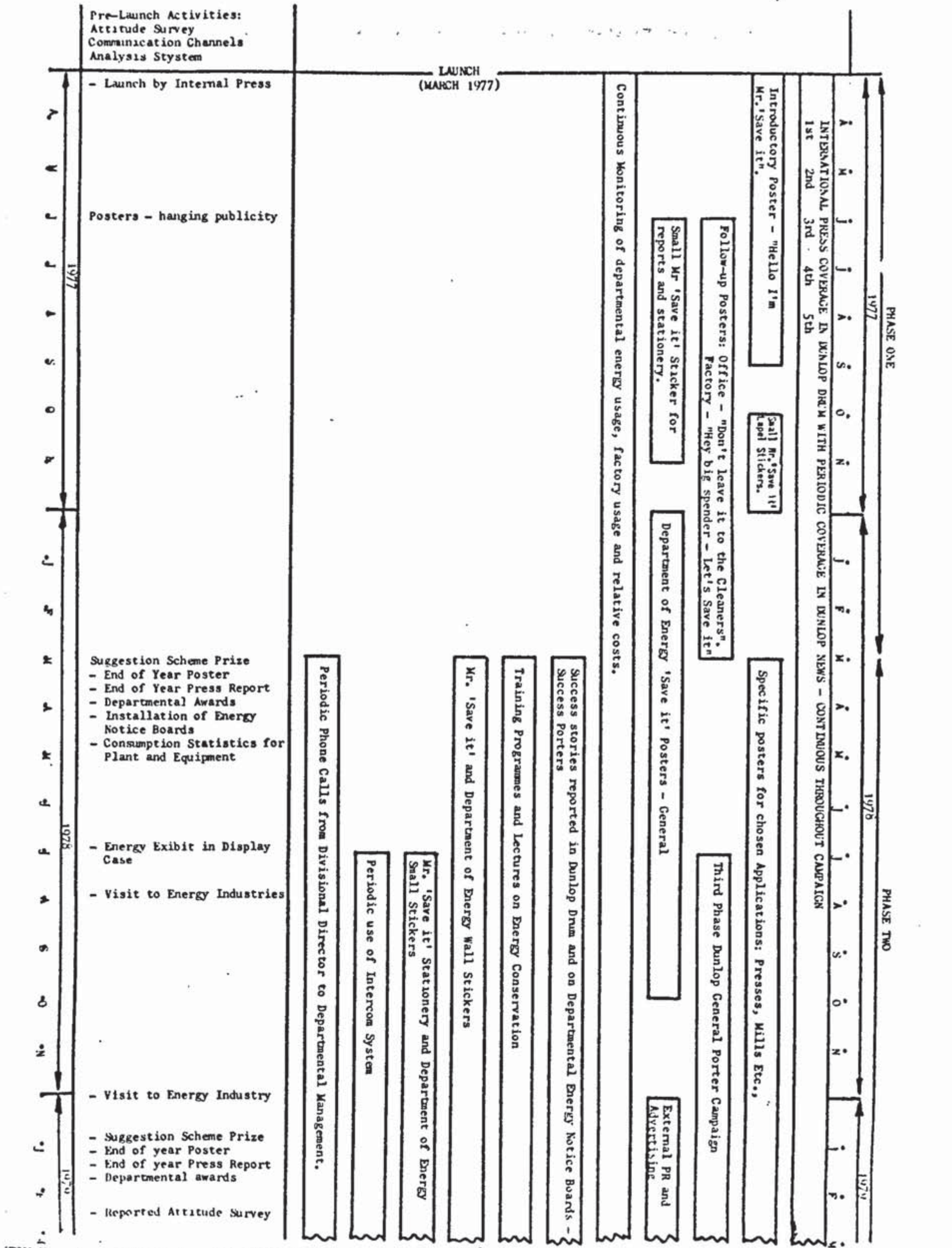


PLATE 3.7A

with statistical information were converted to simple financial figures, or equated to equivalents such as the daily electricity consumption of Birmingham (324 to 327).

Involvement of management and unions on site formed an important aspect to design. Meetings were arranged with all trade and staff unions, senior management committees and individual managers, at which a presentation of proposals and forthcoming discussion took place. From the industrial relations point of view, it was realised that energy publicity, training and organisation could be used as a tool to improve the shop floor and management climate by providing a non-political, common goal.

Comments from the unions generally welcomed such a campaign, especiall with respect to improved suggestion schemes and incentive bonuses. Certain concern, however, was expressed in the effectiveness of the press publicity.

The U.K.T.D. monthly news publication, the 'Dunlop Drum' carried stories on the launching of the campaign and other campaign news items. Regular material on energy costs, trends and save it procedures was prepared for each issue. Both home hints and industrial savings were considered, parallels being drawn between the two. (331 to 337).

Cartoon strips, simple graphs, pi-diagrams and photographs accompanying articles improved the impact on the reader. Readers letters to the Editor provided information on public feeling to the campaign. These were mixed but with a bias towards approval.

3.7.2 The Training Package

An action plan, under the control of the Personnel Department, was formulated in 1976, in which Training Departments in the U.K. Tyre Division were requested to inject energy and conservation into their programmes (94). Outline of the inclusions were as follows:

a. to introduce energy conservation techniques into existing training courses for operatives and supervisors.

b. to establish a short introductory training course for energy managers, energy wardens, foremen and union representatives.

c. to establish short trade training courses for engineering operatives - pipefitters, boiler operators, laggers and electricians.

d. to establish short training courses for project engineers, area engineers and others in flowsheeting and energy balances.

The energy aspects of trade training were well established in external courses. Technical training for engineers also required little embellishment. With the exception of specific information for energy managers, accountants and certain engineers on flowsheeting, energy balances and analysis, for which specific coursework would be needed, the indications on the factory floor called for a general approach.

The problems appeared to be those of identification of losses and implementation of savings. The training, therefore, would have to provide a general picture of energy from source to final usage; outlining costs and efficiencies with specific references to simple 'housekeeping' practice. Two programmes were devised, one a general conservation training package, and the other a paper for use in management development training.

The general package was designed to inpart basic information to any level or employee function. It was not proposed to cut across or replace any of the programmes previously mentioned. The initial format included the items given in Table 3.7.3 (330, 338, 339).

The objectives of the package were to create an Awareness of energy consumption and costs,outlining the need for good 'housekeeping' and providing simple 'Save It' suggestions.

Spotting losses in the factory environment forms an important part of energy conservation. A practical exercise was, therefore, developed to provide delegates with real examples of losses in their working environment,thus emphasising the lecture material and creating openings for discussion.

Each delegate was supplied with a summary of identifiable losses, consequential actions,and a set of tables to evaluate the savings should these actions result (339). Each finding was tabulated (See Table 3.7.4).

The exercise has a four fold advantage -

a. delegates gain awareness in their familiar environment.

b. each obtains basic knowledge of practical housekeeping.

TABLE 3.7.3

Outline of Energy Training Package (338) (339)

1. The general energy picture relating to Dunlop*and including:

   - primary energy sources and location.
   - conversion to secondary energy
   - efficiency of usage.
   - forms of energy and units of measurement.

2. Consumption patterns in Dunlop* including;

   - breakdown in U.K. and Company.
   - breakdown to specific forms (i.e. electricity).

3. Cost trends in Dunlop * including;

   - breakdown in company
   - energy intensiveness
   - price trends and predictions

4. Incentives to save

5. More efficient usage of energy including;

   - general techniques, technical and non-technical
   - check lists.

6. 'Spot the Losses' - (extension of the 'Results' package).

* includes information and statistics on particular factories involved.

Table 3.7.4

Suggested layout of findings and calculated savings to Dunlop

Item		Energy Source	Action Required	Specific Comments	Potential Saving £/year
1.	Unlagged pipework -------- 20 ft. of 4" - Press shop	Process heat	Lag pipework.	It will cost little to get savings.	360
2.	Unwanted lights -------- 50 tubes -------- Material stores	Electricity	Switch them off, take out tubes or provide better switching control.		9000
3.	Air leakage --- Large hole --- Spray painting	Compressed air	Overhaul flange.	Requires shutdown.	11000
4.	etc.				
				Total Saving	20360

c. the results can be fed to site services engineers and the suggestions evaluated.

It is not necessary to include examples of the cost tables but will suffice to add that these consist of financial savings for a variety of energy sources and losses from a range of situations applicable to the particular factory in which the exercise is taking place. (Ref 324 to 327). Table 3.7.5 outlines selected examples prepared for Fort Dunlop.

The paper produced for the Management development courses (313) reviewed energy conservation within the Dunlop organisation but placed greater emphasis on non-technical aspects, namely management, analysis, publicity and training, motivation, accounting and auditing. Traditional problem areas of awareness, incentives, communication, implementation of actions, identification and control were discussed. As with the previous programme, accounts of energy resources, costs and consumption trends were also included.

3.7.3 Motivations

Changes and improvements to a system or operation require the co-operation of people at both the time of conception and implementation. Successful energy conservation in industry depends on employee attitudes, at all levels, permitting decisions and actions to be carried out . Although a study of its own, it was necessary to examine incentives and personal behaviour to establish prime motivators since at Fort Dunlop, attitudes at all levels seemed to be exceptionally poor.

TABLE 3.7.5

Cost tables of selected examples of losses for Fort Dunlop

Item	Energy Source	Loss Rate	Cost
1. Leakage	Steam	various sized holes	£ / year
2. Leakage	Process hot water	various sized holes	£ / year
	Domestic hot water	" " "	"
	Process cold water	" " "	"
	Domestic cold water	" " "	"
3. Leakage	Compressed air	various sized holes	£ / year
3. Unnecessary lighting	Electricity	numbers of tubes	£ / year
4. Idle running of machines	Electricity	for an hour a day	£ / year
5. Heat Losses	Steam/		
- unlagged pipes & flanges	Hot Water	various pipe sizes	£ / yr/ft
- flat surfaces	"		£ / yr/ft
- domed surfaces	"	various diameters.	
6. Ventilation	Hot air	Windows, doors and openings	£ / year
"	" "	Air curtains	£ / year
"	" "	Roof vents and fan extractors	£ / year

Assessment of motivators can be clarified by use of a matrix, where various motivators are compared at various functional levels. From the matrix a motivation index can be derived, weightings being given to each category. (See Figure 3.7.6).

Interpretation of the results produces two possible lines of action. The first infers the use of existing motivators appertaining to specific levels. The need for savings can be identified with these incentives and relayed through normal communication channels - publicity, training, reports etc. A typical example would be the emphasis of increased energy intensiveness to senior and departmental managers.

The alternative method would be to allocate motivators to specific groups with the use of intensive publicity, and follow this with the standard 'need-to-save' procedures. An example would be to create in all employees a sense of duty towards future generations. This is more difficult to achieve and must be considered 'long-term'

In the Dunlop campaign the former technique was used. Although other incentives existed, the prime motivators at all levels were personal finance and security. The following proposals resulted, implementation of which has to date been limited:

a. extension of the existing Dunlop Suggestion Scheme to include energy, financial rewards being given to useful ideas Financing of a separate scheme was not recommended since many energy savings were linked with other criteria. The budget set for the scheme was, however, increased, rewards being a quarter of one year's saving up to £1,000 maximum.

Table 3.7.6

Motivation Matrix

Motivator	Level	Goverment	Shareholders	Senior Management	Departmental Management	Supervisors & Foremen	Operatives	Union Representatives	Production	Engineers	Scientists & Technologists	Clerical Staff	Accountants	Cleaners & Security	Marketing
Prestige		2	1	2	1						1		1		1
Duty		1		1						1	1				
Professional Pride										2	2				
Finance - Company			2	2	1	1		1	1	1	1		2		
Finance - Personal			2	2	2	2	2	2	2	2	2	2	2	2	2
Finance - Country		2	1	1							1		1		
Personal Security			2	2	2	2	2	2	2	2	2	2	2	2	2
Environment		1		1	1			1		1	2			1	
Legislation				2	2	1		1	1	2	2				

1 = some influence 2 = strong positive influence

b. Special award for the best energy suggestion of the year. The most beneficial reward was thought to be a weekend holiday on the continent, from which publicity could be gained.

c. interfactory/inter-department energy challenge prise (94). Rewards were not to be financial but a percentage of the saving was to be re-invested in improving the factory/ departmental working environment.

d. programme of energy competitions with energy prizes i.e. loft insulation, time clocks etc. for domestic use. These were features of the Dunlop Drum and included - 'best letter of the year', 'write a slogan' etc. (94).

Employee motivation through incentive need not be monetary. For example savings made may be put to improving the working environment It is also important to report success. Any returns for effort will encourage further effort.

Some debate whether energy savings should be reflected in the pay packet. J. A. Bladon (102) argued that financial reward for improvements made was poor practice, since it was already the employees job not to waste energy. This, however, is negative policy. If improvement is required and reward through a possible productivity deal could provide it, then such a scheme has value.

One important realisation is that there is only limited financial incentive from government policy for industry to save energy. Higher costs alone do not motivate savings, a belief upheld by some government reports (1) (8). Proof is given by Britain's poor performance in the industrial conservation stakes. The majority of the price rises are still finding their way through the product to the final consumer. Even financial and technical aids provided by government schemes (29) (30) are little used by industry Perhaps more stringent legislation is the answer.

In the building industry, regulations have tightened heating, insulation and control standards (66). Extension of this to industrial operations, plant and equipment provides the only sure way of ensuring immediate action. Existing legislation on heating levels in public buildings, offices and factories lacks any commitment. Temperature still remains at absurd levels. Clearly energy should be added to safety, hygiene, and environmental pollution; all functions of the factory inspectorate.

In conclusion, motivation of energy is obviously a complex issue requiring specialised disciplines to solve existing problems. The matrix shown can only act as an indicator since substantial proof has not been attained. In reality, a social study is required ascertaining the prime motivators and their weighting at each level; a useful subject for future social science research.

3.8 Summary and Comment

To achieve a meaningful and effective contribution towards energy saving requires the unprecedented co-operation of everyone and the knowledge of a few simple 'housekeeping' procedures. Co-operation demands improvement in public attitude which may result from greater awareness. Publicity and training therefore become useful tools in the promotion of energy conservation in the domestic and industrial sectors.

Whilst improved in the domestic sector,attitudes at all levels in UK factories towards energy are poor to say the least. It is imperative that the gap between the domestic and industrial environment be bridged. This can only be achieved by a carefully designed throughly prepared campaign specific to a particular environment. Ad-hoc hanging of Department of Energy posters will be ineffective and a waste of time.

Training and publicity, although providing awareness and basic information on savings, will not produce a change in attitude. Some source of motivation is essential. Although others exist, the prime incentive is financial. In the domestic sector this is provided by market forces which, together with improved communication and awareness, have produced substantial improvement. This mechanism, however, does not apply to the industrial environment since the average employee feels disassociated from price rises. Incentive, therefore, must be provided by some form of reward.

Success of the Dunlop campaign is as yet unmeasured. Analysis at this point in time would be inconclusive,since the programme is less than half complete. Indications that improvements have been attained, however, have been forthcoming - interest and awareness is apparent through verbal comment, letters to the Dunlop Drum, and a measured reduction in energy consumption during 1977 amongst the non-manufacturing users.

Publicity, training and motivation of energy conservation cannot be taken lightly. Sceptics often doubt the effectiveness of such activities,questioning the cost-benefit viability. With respect to energy savings,this is a fallacy since the potential recouped costs far outweigh relatively insignificant expenditure. Effectiveness of campaigns, however, is often below par due to initiation by inexperienced personnel. Good design, resulting from a multidiscipline approach is essential. Future research might well be suitably spent in analysing the sociological and psychological implications of energy on society,and the possible ways of motivating changes of attitude in the industrial sector.

CHAPTER IV

IDENTIFYING ENERGY FLOWS AND LOSSES

4.1 Chapter Preview

Chapter II has already defined 'Diffuse' energy usage, the category within which Fort Dunlop and other Dunlop activities fall. Resulting from the extensive modelling activities, identification of energy loss, wastage and inefficiency is highlighted as the most inadequate aspect of energy conservation within this sector. Whilst communication, implementation and other facets clearly influence success, determination of where problems occur ranks of primary importance. This chapter deals with the need for sound identification procedures and possible methods by which such achievement could result.

Direct measurement through instrumentation and metering of flows is essential. The degree to which this can be extended within diffuse industries is limited by economic and physical criteria. The following chapter, therefore, discusses the other possibilities consolidated in clear cut procedures for analysing, accounting and auditing energy.

4.2 Identification - The Need and Possible Methods

The analysing of energy flow patterns, consumption levels and efficiencies in many traditional industries is difficult. Whilst process manufacturing patterns may give greater control of energy usage, multi-product batch-type patterns do not. Where batch-type operations exist in large factory sites, which often consist of scattered buildings hastily constructed or adapted from other uses, energy distribution not only becomes complex but individual unit flow rates are often small. As defined in Chapter II, these are diffuse industries, of which Fort Dunlop is a typical example.

Traditional techniques for determining energy consumption and efficiency become time consuming and costly to apply. The economic feasibility of extensive metering is questionable, resulting in deficiencies in the monitoring systems and consequential inadequacy in identifying ineffective usage. It was, therefore, pressing to evaluate the existing situation on this site and to seek alternative means of assessing energy flows, losses and inefficiencies. If it were possible to identify these clearly, there would then be a sound basis from which a conservation programme could result. In consequence, the remainder of the thesis has been devoted to this aim

4.2.1 The Objectives

From the postulations and hypotheses obtained in Chapter II, the basic need was clearly to identify areas where energy savings could be realised. This required a systematic approach to the existing problems inherent in the systems of measuring, analysing and monitoring usage. To these aims the following were formulated:

a. To review the existing methods of measurement, analysis and recording of energy flows exemplified within Fort Dunlop.

b. To investigate methods by which the existing system might be improved.

c. To investigate alternative procedures for measurement and analysis of usage.

d. To formulate a package for improved measurement and control of energy in 'diffuse' industries.

According to O Lyle (6), "Measurement of losses in a bad plant is impossible and pure guesswork!". For diffuse energy users employing simple metering this is true. More recent and advanced techniques may have improved the situation. It is likely that no one procedure alone will be successfully deployed but that it is more likely to be a combination of methods. To ascertain such alternatives it is necessary to review all the possible procedures.

4.3 The Fort Dunlop System

It was generally believed that the standard of metering on the site is inadequate for effective control of energy. The problems associated with metering, based as a survey carried out, are described in the ensuing paragraphs.

Annually the Works Accounts Department produces a cost centre disposal plan showing the expected energy consumptions, as metered, for town water, natural gas, electricity, steam, compressed air and borewell water. All subsequential apportionments are laid down, including hydraulic and cooling water consumption, based on metering of electrical consumption required to provide these services. All apportionments are pre-determined by engineers.

4.3.1 Electrical Consumption

Electrical energy is primarily metered at each main feeder entering the factory. Subsequent major consumers are recorded by secondary meters, the sum of which in a particular department will provide the total consumption for that area. Items of plant having significantly large electrical loads are each provided with individual meters. For smaller consumers, a number of pieces of plant relate to one meter, apportionment based on engineering assessment being made thereafter.

Main meters are read by both the Electricity Board officials and Fort Dunlop electricians. In addition to this, the remaining secondary meters are divided into North and South zones. Within each zone, an appointed electrician carries out weekly readings. Of the total 390 electrical meters installed, 206 are read each week.

In addition to actual meter readings, apportionments also reflect the activity on the shop floor, measured directly from recorded man-hours, product outputs or completed jobs. The requirement for cost data in advance of the monthly electricity bill, necessitates a pre-estimate of the price level for electricity used. The actual bill depends on criteria such as maximum demand as well as the units used. Flexibility in computation is consequently built into the system, so as to account for these cost discrepancies.

In practice, accuracy and reliability of measurements recorded are questionable. Difficulties occur for the following reasons.

a. Meters are not conveniently placed for ease of reading.

b. The dial visual displays are mostly of the traditional clock type (few digital meters are in use). In addition, the protecting glass is often dirty, scratched or covered in condensed water.

c. Variation in the order in which meters are read and synchronisation of the timing of readings each week result through changing of meter readers.

d. Lack of synchronisation of Electricity Board readings with Dunlop readings results from incompatibility of the accounting periods.

e. Meters can themselves be inaccurate, albeit that for normal operation the mean error should not exceed ± 0.5%. Fouling, corrosion and other factors can, however, lead to failure and hence inaccuracy.

f. Numerity of readings accentuates error at any stage from meter reading and recording to punching of computer input and processing information.

g. Finally, even assuming all readings are accurate and taken at a synchronised time, apportionments made thereafter are mostly based on obsolete criteria and, therefore, provide misleading data in subsequent reports.

Due to the disparity between the sum of the primary meter readings (assumed to be accurate) and the sum of the secondary meter readings throughout the factory, brought about through losses in transformers and distribution, reading error, meter error or calculation/reporting error, it has been necessary to compensate for differences by apportioning the loss or gain to each cost centre according to a pre-determined budget plan. To do this a fictitious meter number has been incorporated into the computation process, the value of which is this discrepancy. This value is reported along with weekly data output and provides a suitable measure of meter reading accuracy, budgeted at ± 4% of total consumption. In practice, this level is often exceeded.

In addition to this, the computation process will also make the assumption that readings which are twice as high or half the planned budget are inaccurate and should be rejected; the value of the annual average being adopted in its place. Usage, therefore, becomes a function of expected and not actual consumption. The adverse effect on efficient control of usage is obvious.

One large electrical consumption item is lighting. It is apparently impossible to separate lighting loads through individual metering. Along with non-production consumptions, lighting is apportioned on some basis of floor area or personnel employed.

Supplementary to actual electrical energy consumed, maximum demand and power factor measurements are recorded continuously throughout the day. Metering is carried out at the main feeder station.

The enormity of error in measurement of electrical energy consumption has led to certain recommendations:

a. Metering should be revised to incorporate a systematic sub-division from main meters to departmental metering and finally to individual plant metering, should load levels warrant measurement. At present departmental loads are made up and metered from a number of feeders, brought about by 'piece-meal' factory expansion, the summation of which provide the total for that area.

b. Restriction of the number of meters to a critical few must be urged.

c. Meter read-outs should be digital.

d. Preference should be given to automatic monitoring and control systems to facilitate synchronised and rapid measurement throughout the factory.

e. Should manual readings to be unavoidable, a sequential and ordered pattern should be developed and the capabilities of the meter reader be assured.

f. Meters should be repositioned to facilitate ease of reading.

g. Records based on 'activity' should be viewed with care since these are open to fiddles.

h. Possibility of employment of alternative means of assessment, such as statistical or regression techniques, should be investigated. Lighting loads may be reflected by evaluation of electrical overhead calculated from regression curves for load - production level assessment.

i. Disparity between Electricity Board and Dunlop reading times should be absolved through negotiation.

Electrical Energy is relatively easy to control and measure. Meters are cheap and easily installed. Feeders are comparitively simple to provide.

4.3.2 Natural Gas Consumption

Primary gas input from the Gas Board is metered into the north west end of the factory, and into the 'B' and 'K' block complex from British Leyland. Secondary metering takes place at various points throughout the factory, (8 meters in total). Readings are subsequently followed by apportionment to cost centres. The major consumption at the boiler house is obtained by difference.

Tariff charges necessitate the segregation of use to:

a. domestic - sports club, canteen, training

b. industrial - machine tool, production, dynamometer

c. interruptable supply - boiler house

Quality of gas supply, such as calorific value and pressure are not recorded.

Unlike electricity, gas metering is expensive and is therefore limited to essential locations. Apportionments are, however, deemed fairly accurate due to the system being more modern and newly installed. Problems arise with co-ordinating Gas Board and Dunlop reading times.

As with electricity, distribution of meters is wide spread and they are not always read in the same order or at the same time each week. Whilst integrated displays are mostly used for ease of reading, centralised automatic measurement would help to alleviate inaccuracy. It is also recommended that the boiler house, the major user, be continuously metered, with a permanent record of gas pressure and calorific value being maintained. Extension of secondary metering beyond the present 7 meters is severely restricted by economic feasibility. Adoption will largely depend on the gas load required at the point in question. Portable meters, which can be plugged into a boiler feed, might be suitably employed.

4.3.3 Oil Consumption

Oil imported into the factory is based on tanker weighing at the weigh-bridge and the volume pumped by the tanker into the storage tanks. A more reliable system would be to base invoices entirely on a weight criteria.

Due to the complete lack of metering of oil consumed by the boilers, it is impossible to obtain weekly accounts of either consumption or boiler efficiency beyond a tentative assessment based on tank level indicators. There is obvious need to improve this situation if control of primary conversion is to be maintained.

4.3.4 Propane, L.P.G. etc.

Consumption is measured on bottles bought in, the only possible check of rate of use being by weight. These only constitute intermittent use and do not warrant too much consideration.

4.3.5 Town Water Consumption

Birmingham Corporation water is measured into the site by 5 main helex meters. A secondary system, incorporating some 20 meters, records consumption in the power plant, boiler house, production, engineering and technical departments. Some domestic metering is provided for the canteen, training school and office blocks. As with the majority of domestic users, apportionments have had to be made throughout. Much of these are inaccurate being based on obsolete criteria. Like electricity, over a period of time many water tappings have crossed the boundaries between one cost centre and another. Hence Works Accounts reports are for the most part inaccurate. Town water measurement typifies the need for in-depth surveys into all service supply, distributions and apportionments.

Meters are widely scattered over the site: some read in gallons some in cubic metres: some are digital some are the traditional clock type: most are inaccessible, dirty or underground. Meters are read regularly every Friday, although not always in the same order or at the same time. Meters are not read at all during factory shut-down periods, even though water is still being used.

Inaccuracy occurs for similar reasons to those given for electricity, although numerity is not a particular problem. In contrast to electrical meters, however, the helex meter can only 'under-read'. For the case of town water there is need to standardise and move towards centralised automatic monitoring. Meter reading is not necessarily the major problem. Apportionment inaccuracy contributes the major error.

4.3.6 Borewell Water, Circulating Water and Hydraulic Consumption

Water pumped from any or all of five borewells is metered over a 'V' notch weir system, incorporating a level indicator linked to an integrator. Subsequent usage, mostly for cooling water, is based on apportionment. Control of primary borewell make-up to the system is based on circulating water temperature, the level of which inspires an operator to turn on or off a borewell pump. The residue goes to drain.

There is little or no control of the use of either borewell or circulating water. Consequently a need to study the apportionment system and to survey the distribution is paramount. With the ever increasing pressures to substitute town with borewell water, further metering will need to be installed.

Hydraulics, either departmental or from the centralised pumping station, are not metered directly. The assumption is made that flows will be proportional to the electrical consumptions of the pumps, which are metered. This is not so since the pumps run continuously on full load whether there is a demand or not. The exception is the 2000 psi accumulator which is isolated by a limit switch. To meter all hydraulics networks would be uneconomical.

Rather, it would be better to install load following variable speed motors, and by metering the electrical consumptions, the flow calculated. This applies to all pumping operations whether they be for hydraulics or cooling circuits.

4.3.7 Steam Consumption

Steam is the major form of energy used in Fort Dunlop.

At 21 bar and 280°C it is metered into the 16 inch main from the boiler house. Thereafter, it is metered by some 30 orifice plates throughout the site, some of these measuring process steam, some non-production steam and some heating steam. In the past, control and measurement of steam usage to production departments has been poor. With the advent of the new steam main this improved. Each is now metered for total usage, from which a tertery meter determines the heating requirement. Completion of the distribution system will greatly improve measurement of flows to non-production areas as well.

Most difficulties arise after the secondary metering. Like all fluid meters, orifice plates are expensive to install and cannot be justified for small flows. Apportionment becomes necessary. The piecemeal addition of steam distribution has brought about live steam connections across departmental and zone boundaries; from process to heating mains; and from production to non-production areas. The apportionment system is, consequently, archaic and leads to total inaccuracy.

Unlike most other forms of energy, there are also large losses in the distribution system. It is therefore desirable to meter at the point of consumption. Economic feasibility prohibits this. Introduction of alternative means of measurement is necessary to determine effective usage. Thermography provides one solution. Similarly, through regression analysis techniques linked to useful measurement, it is possible to determine the energy overheads and losses in distribution.

As with water, a large number of weekly readings require monitoring; collection of which involves a large area. Often meters suffer from inaccuracy through malfunction and damage. Often there are instances where orifice plates have been re-calibrated without alteration to the 'multiplying' factors. All these lead to the continual inaccuracy.

Continuous chart recording, automatic and centralised monitoring, and remote control of steam consumption is imperative for all major consuming areas. Updated surveys of the distribution system and necessary apportionments are essential.

In addition to physical consumption, it is necessary to monitor the conversion efficiency of the boiler house and the steam condition. To this end, logs are made each shift. These, along with all consumption charts, provide an excellent way of checking for inefficiency. More often than not, however, they are simply filed without so much as a glance.

4.3.8 Compressed Air Consumption

Singularly the most expensive form of energy used at Fort Dunlop, the reliability of air metering and control is unbelievably poor.

Air is generated at three pressures and yet only the 8.2 bar supply is metered at generation. Provision was made in the past to monitor the 11.9 bar and 16.3 bar consumption but this has twice become obsolete.

Downstream, a further 16 secondary meters measure flows to specific production departments and other users. Like steam, metering is expensive and much reliance has to be placed on apportionment. With the problem of pressure drop through lengthy distribution, it is desirable to measure the final usage. Economically this is impractical. Overheads need to be determined by an indirect method or by regression techniques.

Centralised control and monitoring through automatic data processing is a sure way to improving the present situation. Certainly there is a need to monitor air flows at all the generation pressures. There is also the need to survey the distribution and re-apportion those flows which cannot be measured.

4.3.9 Condensate Return, Effluent and Sewage

Condensate is collected in three secondary zone tanks, each metered by an integrator, and pumped and metered along with miscellaneous returns into a main collection tank in Tyre 1. The return to the boiler house is finally metered and charted before passing through the base exchange units.

Accurate condensate metering has always been a problem. The sum of secondary meters never equals the primary total, which in turn is rarely compatible with the amount of condensate reaching to the boilers themselves (calculation by steam/cold water make-up difference). The reason for the first discrepancy can only be inaccurate metering or poor reading. The second is almost certainly due to physical condensate loss through the pressure relief valve.

It is important to recover as much condensate as possible. Although metering does not measure primary energy use, it is still necessary to achieve accuracy. There is a need, therefore, to improve metering from both primary and secondary returns.

Pollution controls necessitate the measurement of trade effluent temperatures and flow leaving the site. Flow is charted continuously over a 'V' notch weir and measured on an integrator. In addition domestic and industrial sewage is a chargeable item and must also be metered. This is achieved by means of a conventional orifice plate and integrator.

Due to the influence of storm water and the discharge of effluent from other factories into the Fort Dunlop culvert, only rarely will the sum of sewage plus effluent equal the total Fort Dunlop water input. Occasionally large discrepancy can be blamed on a fault in the metering. For the most part, the measurements are adequate.

4.3.10 Production Output Measurement

The method by which departmental output is measured will vary throughout the factory. Compound and Fabric Preparation Departments (C.P.D. and F.P.D.) rely on weight measurement; the difference between the sum of the input weights and the weight of the final products equals the scrap. Most making and moulding departments, on the other hand, work to numbers of beads, raw covers or finished tyres produced. The weights of these are known, and so in theory the total input weight can be compared with the final departmental output to give the scrap figure.

In practice the scrap is mostly arrived at through inspection of the article produced. The total factory output is obtained from numbers of tyres produced as related to weight. In all cases, the basis for performance comparison reverts to weight of product produced.

The problems involved with accurate measurement must be obvious. Human error, fiddled figures, physical waste from ground or strip rubber all excentuate the inaccuracy. It is necessary that production output be accurately recorded so as to provide the basis for energy performance comparison. As it is, weight is not a particularly suitable means of assessment.

For the purpose of energy efficiency calculations for C.P.D. and F.P.D., no deduction is made for inter-factory sales (I.F.S.) of the product produced. If the total steam consumption was 'X', the product weight produced 'Y', and the I.F.S. 'Z', on present performance calculations the specific steam consumption is X/Y, which is a larger figure than the real figure of X/(Y+Z). Clearly this disparity needs to be corrected.

Similarly, the specific energy consumption for a remoulded tyre from Tyre 6 or Tyre 7 is based on the weight of new rubber tread added to the existing carcass. In the moulding process, however, it is still necessary to heat part or all of the carcass as well as the new tread. Based on tread weight only, the efficiency of steam usage looks appalling.

4.3.11 General Comment

Large sites, with diffuse energy usage, of a variety of type, and used for a multitude of purposes present control problems. Accurate measurement is difficult to achieve. Without meaningful data, however, energy accounting and subsequent analysis become redundant. Consumption and costing data is only as reliable as the information gathered by the engineers. The following summarises the general problems: (see also figure 4.3.1)

a. Diffuse usage constitutes diverse distribution of small flows, making metering further down the line uneconomical, thus inferring some form of apportionment. Even still, a large number of meters require reading. These often have complex displays in a large variety of units, are in inaccessable places, distributed over a large area, and are dirty. All have a direct bearing on the measurement error, not least from the extensive computation required. There is a clear need to restrict the number of meters to essential flows.

b. Properly maintained meters, for the most part are accurate. Naturally failure can occur. Planned maintenance is one way of ensuring accuracy.

c. In the past metering has always taken second priority, under other expenditure. Electrical meters were cheap, consequently larger numbers have been installed. Orifice plates are more expensive and often deficient in numbers. In place of the meter, down-stream costing must therefore rely on apportionments. Today, these are still based on the past and now obsolete criteria. Apportionment requires continual updating brought about through regular review of energy services and distribution. It must also be flexible, preferably

FIGURE : 4.3.1. - FORT DUNLOP METERING - GENERAL SUMMARY

	PRIMARY METERING	SECONDARY DEPT. METERING	LARGE USER METERING	METER READING ERROR	METER ERROR	APPORTIONMENT ERROR	POSSIBLE MORE METERS	POSSIBLE AUTOMATION	SURVEY REQUIRED	POSSIBLE REDIST-RIBUTION	ALTERNATIVE METHODS REQUIRED
Electricity	Feeders	-	206	L	S	L	REDUCE	P & S	YES	YES	YES
Natural Gas	2	7	-	M	S	M	SOME	P & S			
Oil	-	-	-			L	P	P			YES
Propane etc.	-	-	-				NO	NO	YES		
Town Water	5	+20	-	M	S	L	SOME	P & S	YES	YES	YES
Borewell W.	1	-	-	M	M	L	S	P & S	YES	YES	YES
Circ. Water	-	-	-			L	NO	NO	YES	YES	YES
Hydraulics	-	-	-			L	NO	NO	YES	YES	YES
Steam	1	+30	-	M-L	M	L	SOME	P & S	YES	YES	YES
Comp. Air	1	16	-	L	L	L	YES	P & S	YES	YES	YES
Condensate	1	4	-	M	L		NO	P & S	YES	YES	
Effluent	1	-	-	S	M		NO	P			
Sewage	1	-	-	S	M	M	NO	P			
Prod. Out.	YES	YES	YES	L							

P = Primary Metering
S = Secondary Departmental Metering
L = Large
M = Average
S = Small

Alternative methods include : remote sensing, thermography, statistical and regression techniques etc.

reflecting some other measurable factor such as production activity.

d. Much metering is also obsolete, measuring flows which do not represent the original specification. It is impossible, on the grounds of economic feasibility and physical numerity, to meter every small energy flow.

e. One problem is the amassing of readings and the synchronisation of these with a specific time each week and with the timing of the electricity and gas board readings. Continual chart records are one way of solving the problem, but complete automation of data gathering is believed to be the ultimate goal.

f. It is essential that drawings of distribution mains be kept up to date. Each meter should be clearly numbered, the corresponding conversion factor being updated with change and suitably marked on the case.

g. Without full automation, the responsibility laid upon the meter reader is substantial. It is necessary to appoint readers of sufficient intelligence and standing to make accurate readings and interpretation, verify the correct meter operation, and to liaise with the works accounts. Data collected on a routine basis must not be examined in a casual manner. They must be considered carefully by a competent person who is aware of the interpretation. Finally data must not be manipulated to suit what some think should be the correct operating conditions.

h. The present system fails to satisfactorily segregate consumptions; ie. isolation of production from ancillary usage, or separation of process heating from space heating. Similarly, factors effecting consumption (production output, ambient temperature etc.) are not accounted. Adjustment must be made to reconcile these effects.

All in all the message is clear. Under normal physical, environmental and economical constraints, the probability of obtaining useful data by the present systems at Fort Dunlop and other diffuse industries is low. Automation may help to eliminate some of the error. However, if the objective is to determine where, how and in what quantity energy is being used, examination at the final point of use is necessary; but, regular permanent monitoring by conventional means is impractical.

Primarily it was necessary to develop a system or systems for isolating specific inefficiency. Secondly there was a need to develop a form of computation which will adequately account for effectiveness of usage. Whilst the latter plays a part in identifying misuse of energy, possibly even to the point of loss, it is the former which is discussed in detail throughout this chapter. Chapter V devotes attention to statistical techniques used in formulating the energy efficiency models.

4.4 The Classical Approach (56)

Whilst intrinsically an exercise for back room scientists, appraisal of technical feasibility for effective energy usage is best viewed from academic theory. Extension of such theory to the real world of industry bears a meaningful contribution to identifying energy wastage and offers more suitable alternatives to present practice, albeit that this is long term. Appendix H discusses the theoretical approach to identifying inefficiency through examination of thermodynamic availability.

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 classical case of known inefficiency, which to date has produced little interest beyond tentative investigation into the replacement of conductive heating by the microwave alternative.

It is believed 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. Classical thermodynamic availability, constructed originally by Gibbs and further developed by Kennan (135), is believed a possible foundation for improved identification at source.

4.5 Work Study, a Technique in Identifying Energy Loss

Productivity in its broadest sense is the quantitative relationship between what is produced and the resources which are used. Distinction between production and productivity is obvious. Variation in production volume need not produce comparable change in productivity due to operational overhead. Declining production output is rarely accompanied by a constant level of effective energy usage. Instead, specific consumption increases.

Productivity is affected by:

a. Basic nature of processes employed.

b. Amount of plant and equipment employed.

c. Efficiency of plant and equipment employed.

d. Volume, continuity and uniformity of production.

e. Utilization of manpower.

Instrinsically, each item can also reflect the effectiveness with which energy is used. It is sensible to assume that what might relate to improving productivity may also be applicable to energy conservation.

Energy consumption bears strong relation to the use of raw materials, labour, machine capacity, and production activity. (See Chapter V). Low production levels and/or excessive overtime and weekend working significantly reduce the effective use of energy in a plant. It is, therefore, reasonable to suppose that traditional work study methods, used to maximise effective deployment of other resources by time and motion analysis, might provide a significant contribution to energy studies.

Derived mainly from R.M. Currie, 'Work Study' (151), in dealing with an ongoing improvement in operation productivity, there are six lines of attack. (Table 4.5.1.). Each of these reflect stongly the approaches already put forward in Chapters I and II.

4.5.1. Method Study

Fundamentally, method study involves the breakdown of an operation or procedure into its component elements and their subsequent systematic analysis; economy of practice and maintenance of accepted good practice being the prime requisits. The evolved procedure follows the select - record - examine - develop - install - maintain sequence. In identifying energy inefficiency the first three are of importance.

a. Select

Energy cost is the usual basis for the selection of operations, sections or departments likely to benefit from study. It should nevertheless be remembered that it is not necessarily the obvious faults which offer the most valuable improvements. The following indicate where worthwile savings may result:

- poor use of materials, labour, machine capacity resulting in high scrap and re-processing costs;

- bad layout or operation planning, resulting in unnecessarily lengthy distribution, failure to make use of tariff advantages, and failure to recognise the effects of energy overhead in weekend working;

- inconsistencies in the supply-demand pattern causing energy

Table 4.5.1

Work Study Techniques in Energy Loss Determination - 6 Line Attack

1.	Improve methods of operation	SHORT TERM - little or no capital
2.	Improve organisation, planning and control	
3.	Improve manpower effectiveness at all levels	
4.	Simplify and improve the product and reduce variety and operational complexity	INTERMEDIATE - some capital
5.	Improve basic process by R & D	LONG TERM - capital dependent
6.	Provide more and improved physical means of production	

Figure 4.5.2

Recording Techniques For Method Study

CHARTS:
1. Outline Process Chart - Principle operations
2. Flow Process Chart - Activities of men, material & equip.
3. Two Handed Process Chart - Activities of workers
   Multiple Activity Chart - Activities of men &/or equip. on a common time scale.
4. Simultaneous Motion Cycle Charts - Activities of worker on a common time scale.

DIAGRAMS & MODELS:
5. Flow & String Diagrams - Paths of movement of men, materials &/or equipment.
6. Two & Three Dimensional Models - Layout of plant

Figure 4.5.3

Guide to the Use of the Critical Examination Sheet

The Present Facts		Alternatives	Selected for Alternative Development
PURPOSE What is achieved?	Is it necessary?	What else could be done?	What?
PLACE Where is it done?	Why there?	Where else could it be done?	Where?
SEQUENCE When is it done?	Why then?	When else could it be done?	When?
PERSON Who dose it?	Why that person?	Who else could do it?	Who?
MEANS How is it done?	Why that way?	How else could it be done?	How?

to be exhausted to atmosphere;

- high energy intensiveness;

- excessive overtime.

b. Record

According to the nature of the job being studied and the purpose for which the record is required, the recording technique chosen will fall into one of two categories: charts (for consumptions); diagrams and models (for flows, pressures, temperatures and distribution). The information may be obtained by visual observation, calculation, measurement or by means of photographic technique.

The recording methods used are summarised in Table 4.5.2. process charts show the sequence and nature of movement but not the path taken. Flow diagrams are used for this. As with energy analysis, it is necessary to derive a set of symbols to denote the activity function of the energy used. Multiple activity charts and simultaneous motion cycle charts take account of concurrent and consecutive action, thus relating the recording to time. The possibility of reuse of exhausted heat from one process or another, for example, can be identified.

c. Examine:

The critical examination is the crux of the basic procedure. R.M. Currie (151) suggests specific points of approach:

- facts must be examined as they are, not as they appear to be

- pre-conceived ideas must not be allowed

- new methods should not be considered until all the undesirable features of the existing method have been exposed by systematic examination.

The sequence of the examination to which each activity is subjected is summarized in figure 4.5.3.

The questioning pattern ensures that every aspect of the energy consumption activity is examined and that all alternatives are considered fully. From this point, logical deduction indicates the most effective means of improvement. The next stage is to use the information now available as a basis for developing an improved method.

d. Method Study in Energy Conservation

Method study can be used for identification of conservation potential in two ways:

(i) directly as a product of investigation of a work study problem involving all operational activities including labour, materials, machines etc. as well as energy. Typical examples for Fort Dunlop would be:

- wasted energy from maintaining a tyre mould at temperature throughout the week for only infrequent production;

- effective operational planning could lead to the press being 'switched on' for only one day a week.

- wasted energy from operators leaving presses open when not required for production, thus losing radiant heat.

(ii) Indirectly by drawing an analogy to energy analysis; i.e. by using method study technique specifically for energy problems. Typical examples are the determination of the effects of overtime, weekend working and production levels on efficiency.

All employees use and control the use of energy in some way or other, whether this be operation of heavy machines, operation of a typewriter, or simply lighting and space heating. Method study techniques will determine how effectively this energy is used, where the problems occur and how they might be avoided.

4.5.2 Work Measurement

Unlike method study, work measurement aims to measure the rate at which an operation is carried out with the object of assessing performance. In practice, both are complementary activities.

Work measurement can serve the aspirations of energy conservation in two ways.

a. Through the assumption that energy consumption relates to labour activity, direct measurement of work should relate energy usage and hence inefficiency. For example, should it be assumed that:-

x = time taken for one operation cycle

y = lighting capacity for that operation

y' = lighting capacity for the operation plus unavoidable inactivity

z = actual consumption of electricity in the week for lighting the operation

n = the number of operation cycles.

Then:

- The electricity required for lighting the operation during the week = n.x.y

- The electricity required for lighting the operation plus inactivity periods = n.x.y'

- The wasted electricity for lighting = (z - n x y')

- The percentage inefficiency $= \frac{(z - n \times y')}{(n \times y')}$

Hence it can be seen that measurement of time and frequency of operation, when related to energy requirement, can be used to form a budget from which effective usage can be determined. The investigation may of course be complex, i.e. lighting may cover other operations at the same time.

b. The procedure used for measuring cycle times may relate directly to energy consumption, such as the time taken for one curing cycle in a press. Measurement of actual curing time to idle operation will give a level of efficiency for that mould. Thus work measurement can be extended, from labour activity to machine activity, to identify potential saving.

4.5.3 Rates, Units and Dimensions in Work Measurement

Work measurement values are mostly related to standard performance, defined as the optimum rate of output that can be achieved by a qualified worker as an average for the working day or shift, due allowance being made for the necessary time required for rest or stoppage.

Work study makes use of 'the Unit of Work' as a means of measurement. This unit is defined by the organisation carrying out the study. (60 per hour is a convenient number known as standard minutes for most purposes). In this unit provision is made both for the effort called for by the job and for rest allowance. The most appropriate unit for energy considerations is time. The major point at issue is not the definition of the unit of work but the degree of 'rest allowance' (R.A.) or non-productive energy use associated with an operation (i.e. continued supplying of steam to presses not actually moulding tyres, due to time taken for loading and unloading or simply idle use). Figure 4.5.4 represents the practical situations. Naturally the smaller the R.A. the more effective the usage.

Figure 4.5.4

Representation of Units of Work

Work	RA

10% inactivity = Earth Mover Tyres = 3 min. Loading

Units of Work = 30 SM

Work	RA

20% inactivity = Truck Tyres = 2 min. Loading

Units of Work = 10 SM

Work	RA

30% inactivity = Car Tyres = 1.5 min. Loading

Units of Work = 5 SM

RA = Relaxation Allowance

SM = Standard Minutes

Note: Units of work given here are purely for demonstration purposes and are not actual measurements for Fort Dunlop operations.

Assuming that there is no idle moulding operation, the duration of the test period is one hour, and conditions are the same for both cases.

a. high frequency cycles, each of 5 minutes duration having a 30% R.A., will require a total 18 minutes for loading and unloading during the hour.

b. low frequency cycles for larger tyres, each of 30 minutes duration and having a 10% R.A., will require a total of 6 minutes for loading and unloading.

Hence although the actual physical time for change-over is greater for the lower frequency (3 min. to 1 1/2 min.), due to handling of the larger tyre, the actual effective energy usage is better.

If the same assessment were to be made using conventional analysis, the weight of steam required per unit mass of tyre is less for the high frequency low weight tyre since:

a. there is greater thermal mass in the larger presses.

b. the conductivity of rubber is poor causing a disproportionate high increase in time required for a larger tyre to heat up and vulcanise.

Conclusions based on one technique can be misleading since, whilst faster cure-times appear to require less energy per unit mass, limits to the speed of loading will increase the RA to a point where the 'energy' economics could become unfavourable. It would suggest that the optimum condition would be to avoid losses during the changeover.

Microwave curing offers one solution, since the heat can be applied when required. The example does, however, emphasise the need to be aware of all the facts before making the assessment.

4.5.3 Concluding Comment

As compared with the sound scientific theory and method expounded in section 4.4, work study techniques approach the problems from the opposite ends of the scale. Scientific method reviews existing problems from physical limitation and knowledge, thus applying the findings to the real situation. Work study actually looks at the real problem and attempts to derive solution from examination of all the facts and alternatives presented in the factory environment. Whilst the classical scientific approach cannot be discounted, it is limited in the day to day working environment.

If energy = work, and conservation is people dependent, it is reasonable to suppose that identification of energy misuse can be at least partially associated with the work study technique.

4.6 Monitoring and Assessing Effective Usage.

The measurement of the efficiency of energy used at the point of consumption can be based upon the thermodynamic availability required to operate the process. As explained in Section 4.4, one virtue of this method of measuring process efficiency is that thermodynamic availability can be wasted, lost or consumed whereas energy, strictly speaking, cannot. Consumption of thermodynamic availability in a process is, moreover, a direct measurement of the consumption of fuel to operate the process, irrespective of whether the fuel is consumed locally or at a remote site.

Within the confines of academic jurisdiction and controlled environments, assessment of the use and misuse of thermodynamic availability might be justified. For the real industrial environment, however, the concept is impractical, being complicated by the effects of multi-factor controlling variable interference. It is difficult enough to obtain accurate reliable measurement of energy flows in 'diffuse' industries. Even if it is assumed that everything could be metered and that measurements were representative, assessment of efficiency would still be difficult due to the effects of production activity, ambient temperatures etc. Of course analysis of the effective use of thermodynamic availability has its place in the initial assessment of plant and process design. For the ongoing operation, however, performance must be measured by some alternative method. Determination of actual efficiency of energy use can be based upon comparing the amount of energy actually consumed in a process with the minimum amount of energy which might be used to operate the process (56). If it is assumed that the necessary measurements have been made and that these have credibility, the obvious sequel is to provide some means of analysis. Lyle postulates (6) that the 'energy balance' is the key. It is undoubtedly the starting post.

4.6.1 The Energy Balance

Many factories do not know where energy and heat is being used. Neither are they aware of how much steam ought to be used or indeed how much, or how little, they could us. According to Lyle it is quite simple to ascertain such answers with only a little trouble, a few simple measurements and some imaginative estimating. The making of the energy balance generally brings to light the extravagant processes and practices, often leading to substantial saving forthwith.

Every factory has some form of costing system. These can often be so elaborate that they become the master rather than the servant. The ideal, as mooted in Chapter III is the simple system which will give the maximum of information from a minimum of labour and cause a minimum of irritation.

Costing by itself is, however, not enough. For factory control, cost accounting can be misleading and dangerous. Without the energy balance, no account whatever is taken of what consumption should be, but merely ascertains, often inaccurately, how much is being used through the vehicle of apportionment and priority metering. Once the balance has been achieved, the costing department can then provide progress reports, thus enhancing the balance. Lyle goes as far as to claim that for some diffuse industries, appointment of a qualified person to carry out a balance may warrant addition to the salary list, since 90% of steam using factories can save 25% of their steam in two to three years as a result of carrying out an energy balance. (6)

The advised procedure is spelt out in Figure 4.6.1.

The items on the checklist are by no means absolute. The procedure must obviously reflect the factory and system being studied. The adopted system will reflect the initiative of the employee carrying out the task. Success will depend on the individual's knowledge of the factory, understanding of energy, and ability to approximate or guess intelligently when exact measurements or calculations cannot yield a result.

Recording and presentation of the results is of extreme importance. Tabular, graphical and pictorial representation must be considered carefully before selection. Amongst engineers, graphs of seasonal flows, specific consumptions and efficiency variations are common place.

Many experienced services and fuel engineers use what is called a 'Sankey Diagram' (6) (9) to provide a diagramatic way of illustrating energy use and losses. Such a diagram (Figure 4.6.2) clearly indicates the flows, quantities and conversion processes.

Once the initial surveys and energy flows have been completed,it is necessary that a comparison be made with what is actually being used and what ought to be used. It is easy to find out the amount of energy being bought; it is fairly easy to estimate the amount of energy being consumed; it is not so easy to determine how much should be used.

According to Lyle (6), the actual energy needed must not be based as pure scientific theory alone. In contrast to section 4.4, it must be based on reasonable practical considerations. This does not mean that the classical approach is redundant, but suggests that the 'real' environment exerts as much influence on a bogey level as the physical laws of science. The bogey is a reference basis for good and bad operations to which comparison and performance can be assessed.

FIGURE 4.6.1

Energy Balance Checklist Summary

1. Study the existing energy bills to ascertain the energy inputs into the factory.

2. Identify the major conversion processes and secondary/tertiary energy flows (i.e. steam production) and ascertain losses of conversion using the well established techniques (6) (9) (24).

3. Study the existing costing system, factory geography and process operation to select the major consumers represented by departments, processes or individual machines. (i.e. determine boundaries for the system and sub-systems).

4. Survey the existing energy distribution system throughout the site, record all anomalies such as obvious loss and attain a suitable knowledge of where meters are, what they measure and where obvious deficiency prevails. Such surveys can be founded on previous layout drawings but must include a physical inspection since few drawings are ever kept up to date. Judgement must not be made on inspection of the cost accounting system since this is intrinsically derived from information imparted by engineers in the first instant and must, therefore, follow the energy balance. Note, whilst such a survey is being completed, obvious inefficiencies such as leaks, poor insulation etc. must be recorded.

5. Decide on suitable units of measurement, common to all energy flows. The S.I. system is preferred.

6. Ascertain through direct metering, approximation or guesswork the quantitative flow rates for all energy sources including water. This should be relative to separate winter or summer periods and weekend or overtime working.

7. Ascertain the raw material and labour input to the factory as a whole and to the comparable consumption distribution (i.e. departments), plus physical dimensions of buildings, so as to provide a basis for specific measurement. (i.e. MJ/man hour, MJ/m^3 building volume). Similarly, measurement of relative product output, ambient temperature and other wastage of resources such as scrap level will also be useful in analysis.

8. Record all direct energy flows in tabular, graphical or pictorial form.

9. Compute information on specific consumption (i.e. MJ of steam per kg of tyre produced) and all conversion efficiencies.

10. Assess the total picture, carry out further analyses and formulate the most suitable means of measuring energy flow and effective usage, initiating improved metering and re-distribution if necessary.

11. Considering all the known factors, formulate the bogey levels, and ascertain what might be a suitable target assuming certain pre-determined improvements.

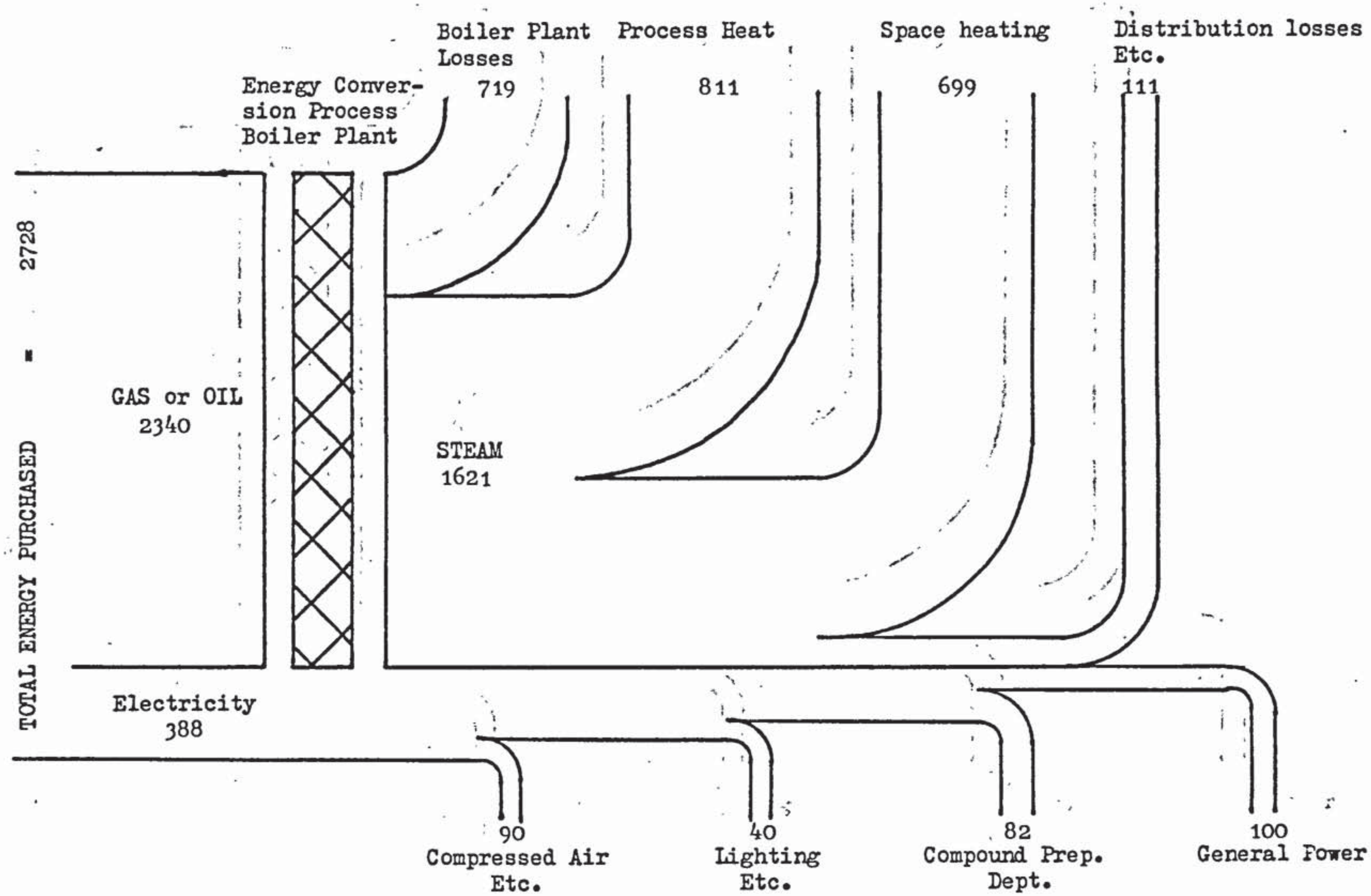
12. Communicate the revised information on distribution, method of metering, apportionments, specific consumption measurement and the bogey or budget levels to the cost accounting system, so that continued evaluation of performance and improvement can be monitored.

Note

Once a survey and balance of a factory's energy usage has been established, it is imperative that subsequent changes to the system are recorded and notice given to the appropriate bodies for alteration to drawings and the costing system.

FIGURE 4.6.2 Sankey Diagram showing a simplified energy account of Fort Dunlop in 1973

Units in 10^{12} Joules



In an industry producing only few products that differ little in character and are manufactured under reasonably similar conditions, setting of the bogey is relatively simple. Where an assortment of entirely different products are manufactured, the bogey is more difficult to fix. Within the Dunlop Tyre operation it would seem foolish to attempt to assert a consumption bogey for all factories throughout the world. Reasons for consumption variation are:

a. Factory building ages and designs vary in different locations. Some are custom built for tyre manufacture (i.e. Dunlop Washington); some are in high aircraft factory buildings (Dunlop Speke); others are in old poorly insulated buildings (Fort Dunlop, Tyre 7), whilst others are in older buildings which have been brought up to more modern standards (Fort Dunlop, Tyre 5).

b. Layouts of production machinery, ages of plant etc. will vary.

c. Type of tyre produced and product mix effect consumption. Radials require more energy than crossply. Long mileage tyres require greater rubber mastication in the mixing preparation.

d. Production operations vary greatly.

e. Some factories do parts of the manufacturing process for others (i.e. compound and fabric preparation for many U.K. Tyre Division factories is completed at Fort Dunlop). Whilst some account is made for this, rarely are all the overheads suitably included.

f. Many sites do not make just tyres. Fort Dunlop carries a conglomeration of 'lodgers' such as Tyre Technical Division, U.K. Group and Overseas central service operations etc. Often these are housed amongst other factory operations, making assessment of energy usage for tyre manufacture difficult.

g. Finally, accounting methods, apportionments etc. differ from factory to factory. Suitable common based measurement is, therefore, impossible.

For bogey setting, therefore, the following rules should be applied:

a. Like products should be compared with like.

b. Allowance should be made for the peculiarities of the system.

c. Quantitative data must be based on reliable measurement over as long a period as possible, full account being made of any seasonal variation.

d. Imagination, clear thinking and possession of all the facts is paramount to the evaluation.

e. On large sites, complete physical measurement is impossible. Calculations of bogeys will have to be made on machine/ process design consumption; floor areas (lighting); building volume (heating); and numbers of employees (domestic water).

f. Finally, the bogey in a factory is not a fixed immutable figure. It must be constantly advanced as techniques improve and better plant becomes available.

The bogey is probably the most important part of the energy balance investigation. The shock received by comparing bogey with actual performance will spur management and engineers to investigate ways of getting nearer to reasonable perfection. Due to the physical limitations of implementation of these improvements, the bogey cannot be used as a means of variance comparison in day to day cost accounting. Instead it tells the engineer what actions might be carried out to improve efficiency and which order of priority they might occur. For day to day performance monitoring, budgets are to be prepared. These account for the impracticality of instant rectification and allow a time scale to be built into the programme. Budgets must of course be derived from the bogey. Fort Dunlop budgets relate to what the usage of energy should be, whilst annually set targets reflect what might be at some point in the future. Managers are committed to a budget/actual variance; they are not bound to targets. Targets should be inbuilt into the budget system, for example, with improvements made should the budget alter greater influence will be brought to bear on getting the job done. Such a decision would be built into the Management Plan and commit management to the programme set down for conservation actions. Accountants fear a resultant negative variance could result from such a procedure through delay in commissioning of improvements and, therefore, shun the concept. However, what is the budget/actual variance but a measure of performance? Energy conservation and commitment to savings is as much a function of performance as any other factor.

A number of balances have been produced for Fort Dunlop and other factories (ref 340-345). Whilst the balance ensures a major tool for discovering loss and assessing potential improvements, several provisos exist:

a. the distribution network for energy is reasonably well known and charted;

b. the metering system is reliable and consistent; the distribution after the meter being known; sufficient numbers of meters being available to give an accurate assessment of energy flows, pressures and temperatures;

c. there are suitable units of measurement and criteria upon which effective usage can be based.

d. past records of consumption, used for trend setting must be clearly understood in terms of reliability and degree of apportionment;

e. Sufficient time is available to carry out the balance, which for a site the size and complexity of Fort Dunlop may take long periods.

Clearly for Diffuse industries, alternative methods need to be found if a quicker and more accurate evaluation of loss is to be achieved.

4.6.2 The Energy Audit

The purpose of an audit is to establish the basic relative costs of various energy forms, the main uses of energy, and the principal points at which there is a waste or inefficiency. It is an obvious extension of the energy balance for a site, but differs intrinsically from the rigorous analysis needed for a balance. G.A. Payne (4) points out that detailed studies and energy balances of specific items of plant or systems should be undertaken quite separately and should not be permitted to delay an initial audit. This need not be very sophisticated or accurate. The aim should be to obtain results quickly and in the light of experience to try to improve accuracy.

The precise form of information collection will depend upon the size of the organisation and its complexity, but most energy audits can conveniently be divided into several phases (4) (20c) (20m). Table 4.6.3 gives a basis for systematic evaluation.

The first collection of data will almost certainly reveal inadequacies in metering and measurement. These should be noted and the necessary steps taken. Checks should be carried out at night, at weekends and during holidays, as well as during normal daytime working, to ensure that nothing is overlooked. A major problem is deciding over what time period representative measurements or estimates should be made and overall efficiencies assessed. An initial audit should concentrate on energy inputs to the system or subsystem. However, energy output may have significance at a later stage, e.g. steam from boilers. With greater sophistication, analysis comes closer to the true energy balance, where all inputs and outputs are measured.

TABLE 4.6.3

A Systematic Checklist for Audit Evaluation

Reference - (4) (20c) (20m)

1. Internal Control Questionnaire -

- 'Control of Energy' : Who is responsible ? How is it monitored ? How is it reported ? Who reviews it ? How is it analysed ? Does it account for all the influencing factors ? How frequent are the measurements and when do they occur ? What are the units of measurement ? Is there a bogey, budget or target ? Is there any forecast facility ? Are there any trends recorded ? Is there any training, publicity or incentive programme ? What is the state of maintenance and inspection ? How is capital expenditure controlled and by whom ? Is there an energy balance ?

- 'Fuel and energy purchases' : What are the sources of energy used ? What tariffs are used ? How effective are major conversion processes (boilers) ? How is it stored ?

- 'Energy Used by various buildings' : Is insulation adequate ? For what period are buildings heated ? How is the heating controlle What is the temperature ? Are there temperature differentials ? Is ventilation excessive ? Does the process contribute to the heating ? What lighting is used ?

- 'Energy Used by various processes' : Which are the large users ? How is plant operated ? At which times are machines used ? Is plant left on or switched off ? Can temperatures and pressures be reduced ? Can operation be altered ? What are the no-load consumptions ? What is the percentage scrap levels ? What are the production output levels ? What is the state of insulation, leakage maintenance etc? Is condensate and other heat recovered or reused ?

Table 4.6.3(b)

2. General Audit Programme Including Buildings

- 'Records of Consumption' : Produce detailed analysis of energy consumed over the most recent year, showing the quantities, specific consumption (i.e. MJ/kg of product produced), efficiencies and cost per unit of energy. Review existing records of consumption and determine reliability. Carry out an energy balance (Sankey diagram) Compare consumption with other locations, previous periods and Bogeys/Budgets to identify inefficiencies. Check meter readings. Test records against invoices.

- 'Housekeeping' : Review maintenance records. Consider planned maintenance. Check that controls are operational and tested frequently. Consider additional instrumentation. Debate maintenance improvements and design changes. Review fuel storage and handling. Review space heating levels, operation and control. Review insulation. Review lighting. Review tariffs and contracts. Minimise peak demands. Review shift pattern working.

- 'Personnel' : Consider level of training and motivation. Consider propaganda and publicity.

- 'Capital Investment' : Review energy related projects under consideration. Review previously unfeasible actions and new proposals. Review the methods of evaluation, decision making and finance. Review efficiency of plant with respect to replacement.

3. Manufacturing Audit Programme (in addition to 2)

- 'Records of Consumption' : Produce detailed analysis of energy consumed over the most recent year, showing the source, uses, specific consumptions, efficiencies and costs per unit of energy. Assess which plant consumes most energy.

- 'Housekeeping' : Review leakage, wastage, inefficiency and unauthorised usage. Review optimum levels of lubrication, energy consumption, temperatures, speeds and pressures. Review control equipment. Check for idle operation. Review and optimise product quality. Review testing of plant, maintenance etc. Review scheduling and operation of main energy using processes.

Table 4,6,3(c)

- 'Capital Investment' : Review power consumption for pumps, compressors, fans and other process machinery. Consider waste heat collection, combined heat and power etc. Consider water and energy recycling.

4. Transportation Audit Programme (in addition to 2)

- 'Records of Consumption' : Produce detailed analysis of energy consumption over most recent year, showing the sources, uses, specific consumptions and costs per unit of energy. Quantify costs of private use of company vehicles. Assess load factors.

- 'Housekeeping' : Consider optimum speeds, loads, distances etc. Review maintenance.

Fuel and Energy Audits, including conservation, have been carried out at Fort Dunlop since 1975 (96). These have mostly taken the form described above but have tended to omit certain actions which could offer greatest potential savings. This is probably due to the evaluations being carried out by non-engineers, the restricted communications between the auditor and the engineers, and a restricted knowledge of the site, plant and operations. Most audits have, therefore, been incomplete and inconclusive.

Whilst Fort Dunlop audits have spent much time on checking actual energy imports against accounts records and invoices, little attention has been directed to reporting consumption trends, performance efficiency improvements, and actual savings as against those projected. Neither have they attempted to check on implementation of actions. Finally, the entire audit argument has been based on the assumption that works accounts records are correct.

Investigations should also review the existing costing system, assess improvements and question the methods of presentation of data. Such information as to specific consumption: effects of weekend working, scrapped production and degree days, has been lacking in the reports. On sites the size of Fort Dunlop, production of an audit is time consuming and difficult. Perhaps the situation requires a full time employee, possibly of engineering extraction and with a knowledge of the plant.

Carrying out an audit of the U.K. Tyre Group should also be undertaken. Such undertakings are intrinsically difficult to implement effectively for the reasons given in section 4.6.1. On the other hand an audit carried out using general overall data can be of some initial use. With these points in mind, an energy audit was completed for the Dunlop U.K. operation (307).

Thus energy audits can be at international, national, company or departmental level. On the macro scale, auditing is derived from a series of statistical returns from industry and commerce, plus a breakdown of sales from energy producers. (13) (14) (36). According to C. Ryder (152) there are two approaches to audits; the first based on energy units, used by plant engineers to assess potential improvements; the second based on monetary values found in cost accounting procedures, where savings can be discovered through budget/actual comparison. Evaluations based on monetary values, however, can prove dangerous since factors such as price changes will obscure any alterations in effective usage. Analysis must be based on energy units alone; the monetary terms must be added at a later stage.

Ryder carries his thinking one stage further into the realms of energy analysis. He attempts to identify the external and internal influences on energy usage by introducing productivity levels, weather conditions and overtime worked. Figures 4.6.4 and 4.6.5 show how from an initial analysis of energy usage in the non-domestic sectors of the U.K. derived from national statistics, Ryder goes on to measure improvements in industry against productivity. Finally he asserts the usefulness of audits in investment appraisal by comparing energy costs with a cost index for plant and equipment. (Figure 4.6.6.). Significantly he ascertains that accountants tend to be governed by one set of rules for capital expenditure and another set of rules for revenue costs. There is a case for rational

FIGURE 4.6.4

ENERGY CONSUMPTION BY NON DOMESTIC SECTOR - %

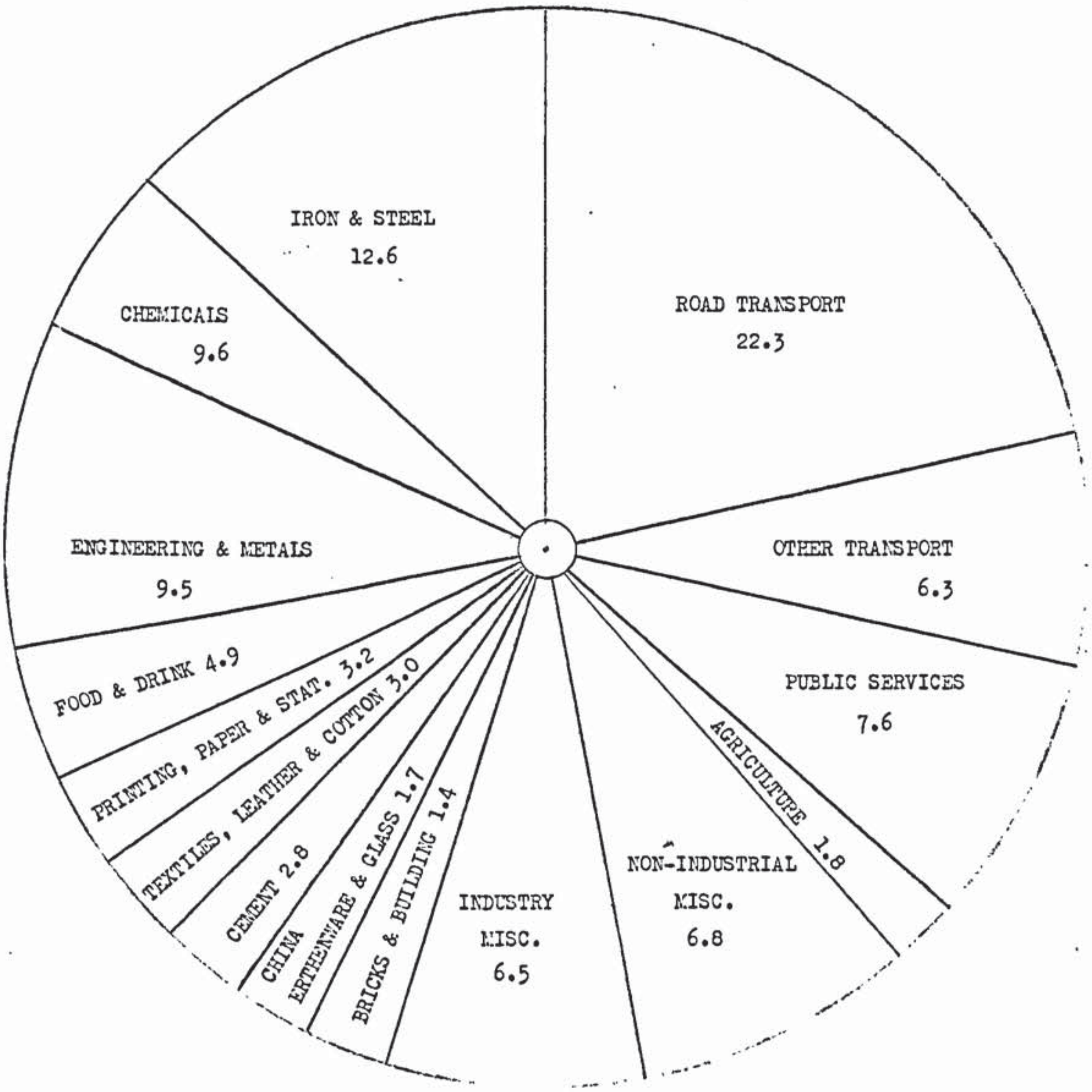


FIGURE 4.6.5

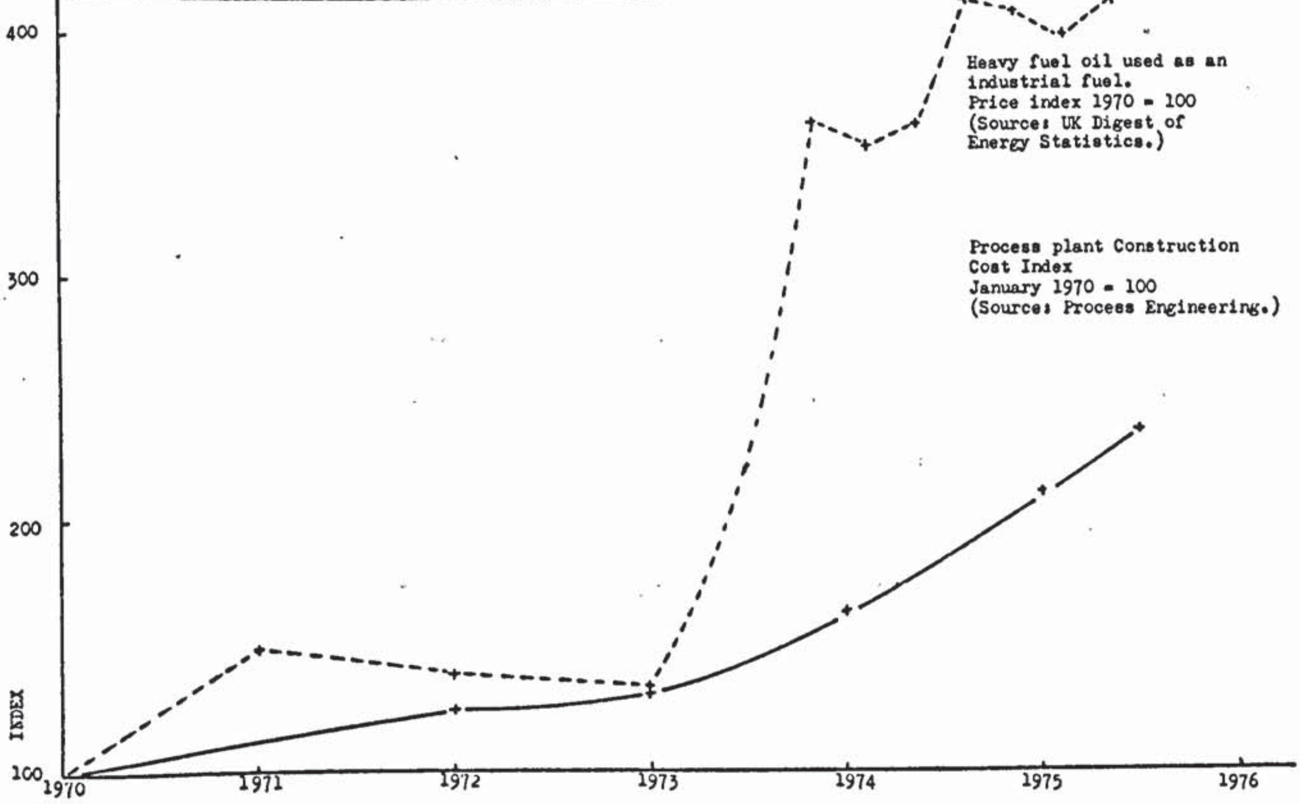
ENERGY CONSUMPTION AND PRODUCTION BY THE PRINCIPAL INDUSTRIAL SECTORS, 1964 and 1974.

Industrial sector	Energy consumption x 10^6 therms 1964	1974	% change 1964-74 (1964 basis)	Production index, 1970 = 100 1964	1974	% change 1964 (1964 basis)
Iron & steel	7299	5481	-20	99.2	87.7	-12
Chemicals and allied trades	2578	4187	+62	69.7	127.6	+83
Engineering and metal trades	3339	4119	+23	85.6	104.8	+22
Food, drink and tobacco	1748	2129	+22	86.4	110.1	+27
Paper, printing and stationery	1334	1381	+ 4	88.5	108.8	+23
Textiles, leather and clothing	1582	1313	-17	88.2	103.1	+17
Cement	1032	1178	+14			
China, earthenware and glass	695	720	+ 4	93.6	117.4	+25
Bricks, tiles fireclay and building materials.	958	590	-38			
Total Industry	22509	23936	+ 6	86.5	106.3	+23

Sources: CSO, Annual Abstract of Statistics and Digest of UK Energy Statistics.

FIGURE 4.6.6

Comparison of energy prices with the cost of process plant



reappraisal of these conventions.

Ryder asks the all important questions,'Do figures really show the true picture, are they meaningful and are there any gaps?'. This move from auditing to energy analysis is a natural progression based upon an absolute requirement to arrive at the true picture.

4.6.3 Direct Use of the Cost Accounting System

Using the information from any energy accounting system, there are seven ways in which useful assessment of performance might be made.

a. Absolute Energy Usage - Energy flows can be measured and broken down from site usage (equivalent to the energy imported and recorded on the invoices), through any conversion processes such as steam raising or compressing air, to department levels office blocks, individual machinery, waste energy processes and final disposal. For most practical purposes, measurement ceases after the production department level, with the occasional meter (mostly electrical) being attached to an office block or machine. At this point, apportionment based on machine/building design parameters, sizes of pipes used for distribution and numbers of employees, tends to excentuate inaccuracy. However, assuming all flows were measured or estimated, it is then possible to determine the proportional distribution of energy usage. Based on this judgement, statistical techniques can then be used to infer a level of loss, on the assumption that largest consumers waste most energy.

The smaller the initial sub-division the greater the possibility of discovering the actual loss. The procedure is naturally dependent on the extent of metering, and the accuracy in reading and processing the information.

Actual consumptions can be split into further categories, such as heating or process steam, factory and non-factory energy. This might be extended to separation of lighting from process electricity and toilet water from domestic supplies. Obviously the greater the separation the more accurate the assessment.

b. Specific Energy Usage - Performance based on absolute measurement fails at the onset since alteration in production output varies the energy consumption. Specific measurement, broken down into similar divisions as before, makes for an improved method. Fort Dunlop presently measures the effective use of energy based on kilogrammes of tyres produced. It would, however, be nonsensical to divide total site figures by production output, so non-production consumptions are removed and considered separately.

To aid in the assessment of the effective use of steam, water, electricity and air, departmental and factory graphs are produced monthly. By comparing performance of one energy source with another, deductions on effective operation may be determined. For example - a sudden increase in specific steam consumption accompanied by a rise in specific water consumption for Tyre 6 would indicate either a blown calorifier tube or passing steam traps. - A sudden increase in specific consumption of electricity accompanied by an increase in specific compressed air could indicate severe air leaks. (See figure 4.6.7.).

This technique only represents production operations. Often data of this kind is not available. Departmental specific electrical and steam usage includes lighting and heating respectively, which are independent of production operation and, therefore, form an 'overhead' when compared with output. Ideally, like non-factory operations, such usages should be considered separately as absolute figures. It must be noted that interdepartmental, or interfactory comparisons cannot be made unless production conditions are similar. Comparisons for one department should be made with either a bogey, budget or previous trends.

Specific measurement need not of course relate to production output. Performance of a boilerhouse will be reflected in the quantity of steam produced per therm of fuel burnt. Effective use of domestic water might be measured as the consumption per manhour.

c. Trend Comparison - Direct comparisons of continuous trends whether annual weekly or hourly, will indicate fluctuation in effective usage over a period of or at selective points in time. This provides an excellent means of performance evaluation of an operational unit. It will not allow for cross comparison between units or systems.

d. Bogey (or Budget) - Actual Variance - Due to the problems of interfactory (departmental) comparison, the variance system has been introduced, whereby at some stage someone has stated what the process, building or transport should use. For either absolute or specific values, bogey - actual variance is a real measure of efficiency; whereas budget - actual variance is a measure which satisfies the management and accountants. In either case, however, the initial standar is arbitrary.

e. Influential Factors and Energy Consumption - Decreases in the level of production are not accompanied by proportional decreases in energy usage. The effects of ambient temperature distribution losses, leaks etc. all influence specific consumption and are not effected by changes in production levels. It is also reasonable to assume that the heating of well controlled buildings will vary with ambient temperature or degree days (20c). Graphs can then be drawn to show the relationship, deviations from which indicate abnormal loss.

Based on the original accounting data, overheads and other effects can be accounted for by graphically comparing specific consumption with production output. Deviation from the curve will indicate subnormal behaviour.

The obvious progression is to develop suitable equations to account for all the variables effecting consumption. Regression analysis of data collected over time will provide arbitrary formulae to do just this. The use of the procedure is valid provided all the influential factors can be identified. There are of course some which cannot be quantified; for example, strikes by engineers, whose normal job it is to turn down the heating when it is too warm.

f. Indirect Assessments - Certain conditions can act as indicators. Increases in flue gas temperature without a corresponding increase in economiser inlet gas temperature could indicate a drop in economiser efficiency. Similarly increased oxygen in flue gas analysis must reflect the state of burner and hence boiler efficiency. High condensate return to the boiler house without corresponding reduction in raw water make-up infers problems with either the hot base exchange units or the relief valves, thus sending hot water to drain.

g. Specific Calculation - The final assessment of performance comes from specific calculation involving evaluation of efficiency from a number of variables. The calculation of boiler house load factors and efficiencies provide suitable examples. Here no special measurements are needed but should be available from the records.

Obviously a great deal of information can be gleaned from the existing accounting system. Within diffuse industries, however, a number of problems emerge which severely effect the validity of basing assessment on such date. To these inadequacies in metering given in section 4.3 are added the following:

FIGURE : 4.6.7

Evaluating Compressed Air Loss by Electrical Consumption

This is a typical example of the use of energy analysis for the identification of energy loss in a factory.

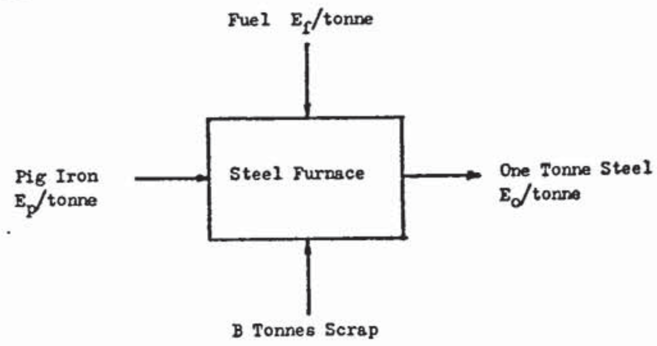
All figures are in electrical equivalent - kwh/kg of product.

	Electrical Consumption Site	Compressed Air Consumption Site
Fort Dunlop	1.45	0.28
German Factory	1.32	0.16
Difference	0.13	0.12

CONCLUSION

The relative in-efficiency in use of electricity consumption at Fort Dunlop could be caused by the in-effective use and generation of compressed air.

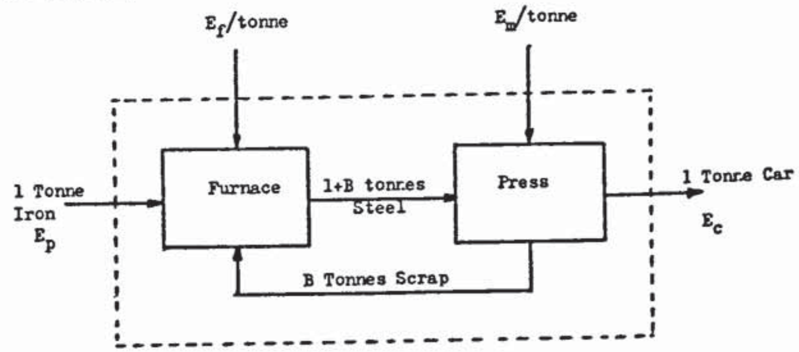
FIGURE 4.7.1



The material and fuel inputs to a steel furnace

(Note: to produce one tonne of output, the inputs are B tonnes of scrap and 1-B tonnes of pig iron.)

FIGURE 4.7.2



The enlarged system including a car manufacturer who generates the steel scrap consumed by the furnace.

a. Should it be possible to eliminate all the differences between individual departments and/or factories, then only would corporate comparison and bogey setting be possible.

b. Bogeys and budgets are purely arbitiary.

c. Only on very broad terms are interfactory comparisons possible. An example is given in the relationship between energy and water consumption, (Chapter V).

It is the deviation from the normal by the subnormal that requires detection. Present techniques are unable to segregate the influences of other factors to effectively detect true wastage.

4.7 Identification by "Energy Analysis"

The definition and functions of Energy Analysis have already been discussed at length in Chapter II. From these philosophical arguments, a natural progression is to reflect the practical implications of the techniques in postulating energy loss identification. This section is devoted to this aim.

4.7.1 Industrial Energy Analysis

The key objective of any form of analysis is the assessment of performance related to some standard. 'Input/Output Table' energy analysis (140b) gives the 'direct' energy consumed in product manufacture as well as the 'indirect' energy content of the incoming raw materials. This can provide, in national interests, the energy requirements for the entire product life cycle. Beyond determining the effect of primary energy price on industrial manufacture, the energy intensity of capital goods and the energy 'profit' for the energy industries, this procedure holds little significance in day to day factory analysis. Two measurements commonly in use are:

a. Energy Intensiveness = $\frac{\text{Sum of energy consumption items}}{\text{Value of the Commodity}}$

b. Energy Ratio = $\frac{\text{Energy Output X Life Cycle}}{\text{Energy Input}}$

Similarly, 'Statistical Analysis' (36) combines selected factual performance measurements, through statistical extrapolation, to formulate information on inputs and outputs for specific industrial classifications. Once again this is of little use for day to day control.

'Process' energy analysis (140b) on the other hand holds potential significance. This comprises of three stages:

a. Identification of net work of processes contributing to a final product.

b. Analysis of each to identify inputs in the form of equipment, materials and energy.

c. Assigning an energy value to each.

Obvious problems arise in defining the system (in this case a factory) and sub-systems (individual processes), in attaching energy values to inputs, incorporating all significant inputs and in knowing what level of detail to adopt. For normal short term analysis the energy content of equipment is superfluous.

Once the energy values are assigned and the loss or wastage determined, subsequent investigation postulates why levels of consumptions occur. (140e). Common influences include: production levels, ambient temperatures, cycle times, numbers of operations, load factors etc. Type of physical plant and product mix may well reflect the efficient use of 'available' energy, often dependent on the level of capital investment. A suitable vehicle for the derivation of such relationships is provided by regression analysis, described in detail in Chapter V.

In postulating theories as to why consumption levels occur, all assumptions and limitations must be fully appreciated. Hypotheses based on uncertain facts processed through statistical computation can lead to misleading results.

4.7.2 Analysis of Effective Energy Usage

It has been stated many times that the basic concepts of energy analysis differ little from the already well established energy balance. This is not entirely true since balances in conjunction with the 'bogey' setting (6) will only highlight loss or deviation from efficiency and are inadequate in judging performance in its entirety. The Lyle theories (6) rely on economic evaluation to come into play once the initial assessments have been made. This is correct since if the true energy performance is to be comprehended,economic analysis cannot effectively isolate the energy content of reprocessed material or feedback loops. There are pragmatic grounds for keeping economic analysis separate from energy analysis,in that it is useful to evaluate any situation independent of the variable influences such as fuel, labour or material price.

There is obvious advantage of looking at larger systems than a single process, department or factory. This can be illustrated by examining a theoretical example concerning a steel works and car manufactures (10c). The operation of steel furnaces can be represented by material inputs, of pig iron and steel scrap; a fuel input (Ef) and an output of steel. (See figure 4.7.1). It is assumed that the energy requirement for pig iron to reach this stage (i.e. mining, smelting and transport) is Ep units of energy per tonne. The steel scrap is not given any 'Gross Energy Requirement' - g.e.r.

From the steelmakers point of view, the total energy requirement per ton of steel (Eo) is given by:

$$Eo = Ef + Ep \cdot (1 - B)$$

This suggests that the larger the scrap input, the larger B, then the smaller is the enrgy requirement of steel. Hence to further energy conservation, more scrap handling plant and equipment is installed on the basis of the simple balance.

Hypothetically, at the same time, a car manufacturer is faced with a choice between two steel presses.

	Energy Consumption per sheet	% Scrap Produced
Press A	10 kwh	10
Press B	12 kwh	0

With the price of electricity increasing the energy conscious car manufacturer installs Press A.

If the fuel input to the press is Em per ton, the scrap being recycled to the steel plant; and if the output car requires 1 tonne of steel, then by the conservation of mass, the pig-iron input must be 1 tonne and the total balance given by figure 4.7.2. However, the fuel consumed in both the steel furnace and car press is proportional to the total mass throughput, which includes B tonnes of scrap over and above the 1 tonne input. Thus the total energy requirement of the car is given by:

$$Ec = Ep + (1+B) \quad (Ef + Em)$$

This shows that increasing the quantity of scrap generated and used increases the energy requirement. The market imperfections involved in this example include the ability of a manufacturer to declare a higher price, the car manufacturer's uncertainty concerning future fuel prices, and the inability of prices to show up a 'system' effect before the investment decision is taken.

To the departmental engineer within a factory, the same predicament emerges. The inherent rubber scrap fed back into the system either in that department or to another part of the factory is not and has not been accountable with respect to energy value. As the percentage of rubber recycled is increased, the 'useful' energy in the production process increases at the expense of performance.

Carrying the technique to its ultimate conclusion, it is possible to analyse an entire system and to determine which decisions will provide the lowest energy intensiveness. I. Boustead and E. F. Hancock (140d) illustrated this point in their analysis of energy consumption in the packing industry, through the new/recycle decision for the bottling of consumer goods. This method may suitably be extended to the tyre industry. Figure 4.7.3 illustrates the possible alternatives within the decision making process; i.e. new raw materials vs reclaimed materials vs retreading vs incineration.

The operations 1 to 6 represent the main production and use sequence. Operation 7 occurs when the tyre is returned for retreading, operations 8 and 9 are involved when tyres are either put through the reclaiming or the incineration processes respectively. If the energy consumed by the i^{th} element is Ei per unit mass passing through the element, then the system energy E_s for n tyres of mass m required by the consumer is given by the equation:

$$\frac{Es}{m.n} = (E1+E2+E3+E4+E5+E6+Em) + a(E7+E8-E1-E2-E6) + b\,(Eg)+d(E10)+e(E8 - E2) + f(E1 - E8) - Kc$$

Where K = energy/unit mass recoverable from incineration

a = % tyres weight to retreading

b = % tyre weight to reclaim

c = % tyre weight incinerated

Em = primary heat energy/unit mass required for moulding

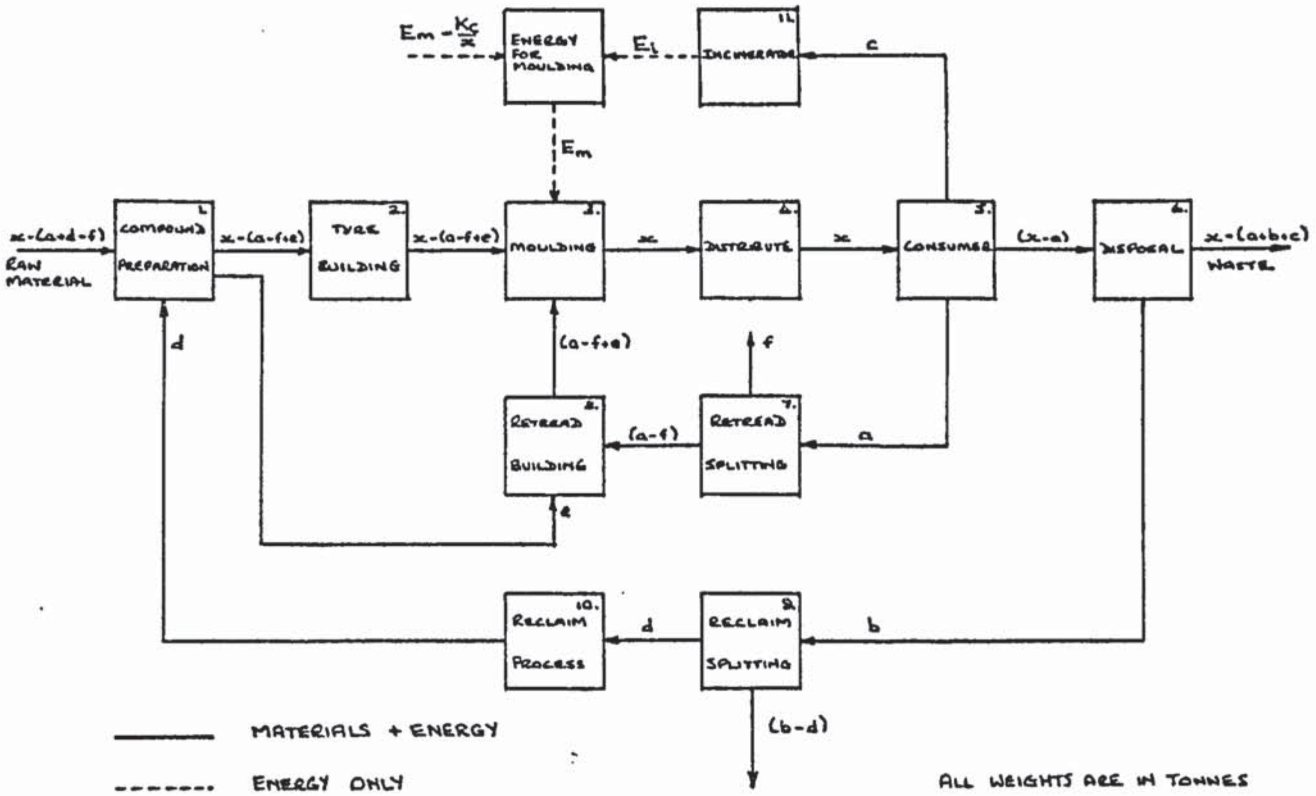
E3 = additional energy/unit mass required for moulding

d = % tyre weight reclaimed

e = % tyre weight supplementary to retreading

f = % tyre weight wasted from retreading

FIGURE 4.7.3 Energy Analysis for the manufacture of tyres



Energy Account

1. Compound Preparation = $E_1(x-a+f)$
2. Tyre Building = $E_2(x-a+f-e)$
3. Moulding = $E_3(x) + E_m(x)$
4. Distribution = $E_4(x)$
5. Consumer = $E_5(x)$
6. Disposal = $E_6(x-a)$
7. Retread Splitting = $E_7(a)$
8. Retread Building = $E_8(a-f+e)$
9. Reclaim Splitting = $E_9(b)$
10. Reclaim Process = $E_{10}(d)$
11. Incineration = $-K(c)$

Energy per Unit Mass for Moulding = E_m Energy per Unit Mass for Each Process = E_1 .... E_{10}

Masses of Products at Various Stages in Tonnes = a,b,c,d,e,f

K is the Incineration Constant elating to the Gross Calorific Value of the Tyres Burnt & the Efficiency of Combustion.

Total System Energy Requirement

$$E_s = x(E_1+E_2+E_3+E_4+E_5+E_6) + x(E_m-\frac{Kc}{x}) + a(E_7+E_8-E_1-E_2-E_6) + b(E_9) + d(E_{10}) + e(E_8-E_2) + f(E_1-E_8)$$

This equation of course assumes that the energy requirements per unit mass within the tyre production process (i.e. elements 1 to 5) will be identical for raw material, rubber and reclaim. Similarly, it assumes that the energy per unit mass requirement for moulding will be the same for new tyre covers as retreaded covers.

Practical application of this general model requires evaluation of the variables Ei, a, b, c, d, e and f. Due to the assumptions made above, it is not possible to give a complete description of all of the calculations needed, but the general approach can be outlined. Each sub-system on Figure 4.7.3. must be analysed further until specific operations are identified for which the energy consumption data is available.

However, assuming the equation is representative of the g.e.r., (= Es/m.n), then the variables Ei, a, b, c, d, e and f can be changed to give the lowest g.e.r. value. The resultant conclusions provide a meaningful analysis of optimum performance and efficiency, which is independent of the effects and economic criteria, market force and political interference.

4.7.3 Comment

The usefulness of energy analysis cannot be disputed. Whilst energy balances have their role to play, there is an obvious need to move towards a more rigorous form of performance evaluation. It is argued that economic analysis provides sufficient information upon which decisions can be based. Through the examples shown above, this reasoning is somewhat unsound. It is imperative, in the light of such influence as changing energy price, that the alternatives be reviewed independent of economic, social and political pressures.

Naturally, neither energy analysis or balances can provide all the answers. In the 'Diffuse' industrial operation there are obvious difficulties. Defining the systems boundaries, identifying the interconnecting flows and comprehending the operational procedures in their entirety provide substantial obstacles to successful energy analysis. Similarly measurement of energy outputs in the form of heated air and water, energy retained in the product, or simple building loss through radiation make it difficult to perform the energy balance. Neither is it simple to detect and evaluate the 'hidden' losses resultant from passing steam traps, fractured calorifier tubes or leaking valves. In practical terms, alternative methods need to be found to the normal metering technique. Possibilities include 'Thermographic' detection of heat loss from complex and widely distributed sources (Chapter VI, VIII and IX); and ultrasonic leak detection for hidden loss (Section 4.10).

Some strategic measurement, however, is essential for the detection of obvious losses and the formulation of energy balances and resultant analysis. It is, therefore, suitable to discuss measurement at this stage.

4.8 Direct and Indirect Measurement

Efficiency in the use of primary or secondary energy can be achieved and maintained only by the careful control of the conditions under which it is converted to produce heat, mechanical power or electrical energy, and in its final consumption. To control any physical condition, a primary requirement is that its value be known. To obtain this information appropriate measurements are required. These include measurements of pressure, temperature, rate of flow, density and gas composition. Associated with these basic measurements are the transmission of their values over a distance, distant monitoring and recording instruments, and remote control of the process.

Many large, complex and diffuse organisations spend large sums of money on fuel and practically nothing on instruments to measure and control. Measurement should be reliable and accurate, but no more accurate than is necessary to do the job. Instrumentation, now in the electronic age, is well established and reliable. Whilst individual meters may be complex in nature, incorporation into the distribution system is relatively easy.

The equipment needed is fairly straightforward. There is great merit in simplicity and robustness.

The rapid expansion of instrumentation in recent years has led to the appearance of a wide range of measuring equipment for sensing and registering the value of virtually all physical variables encountered in industry. A detailed description of all the types would be beyond the scope of this chapter; details of specific equipment can readily be ascertained from catalogues and other literature. Similarly, information on procedures for carrying out specific tests on pieces of plant and equipment can readily be found in the scores of textbooks dealing with the subject (4) (6) (9) (60) (74) (82) (147) (149).

The measuring element can give an indication on a scale, a recording on a paper chart, an integration on a counter or an automatic data logging and control facility. Hence the progression is from simple reaction to a visual dial reading (i.e. a pressure gauge), to reaction brought about by reading a report of measurements, to fully computerised automation. The degree of sophistication will obviously reflect the economic feasibility.

Permanently installed instruments should be used for all larger plant on which frequent or continuous measurements are required. The instruments should be regarded as an integral part of the plant and should be of high quality. They should be carefully installed to protect them from dirt and damage and to facilitate maintenance. Portable test equipment may also be used to take prescheduled measurements where fixed instrumentation cannot be justified.

4.8.1 Instrumentation in Industry: - the Problems

Instruments are tools to be used to provide data upon which decisions can be made. They must be correctly calibrated and adequately maintained. Without measurements, management is impossible. Good management depends upon the successful interpretation of the available data. According to the Watt Committee on Energy - Report 3 (145), instrumentation in industrial and commercial plants, "is either non-existent or, where existing is not working, and where working is providing information which generally is not used to the full". For diffuse industries such as Fort Dunlop, the statement is upheld.

It does not follow that in those industries where professional engineers are supported by instrument engineers that comprehensive instrumentation is always provided. Many engineers are frustrated by the lack of instrumentation or because the system, once effective, has become worn out and no longer applicable to the work in hand. Obsolete or partly effective panels are common; forcing decisions to be based on incomplete data. In other cases only a basic number of instruments have been installed, leaving certain other desirable parameters unmeasured.

Many energy systems have been and are still being installed with inadequate measurement of vital temperature, pressure and flow parameters. The lack of thermostats in offices is just one example. The reliance of many processes on rule of thumb methods shows a disregard for the maintenance of production standards as well as waste of resources. The over-drying or ineffective cooling of materials are two examples of this. Furnaces and boilers of all types are operating on gas or oil firing with no individual meter to give vital data of daily or hourly performance.

In most cases where instruments are provided, whether as a comprehensive scheme or for piecemeal guidance, it is often found that, where data needs to be obtained, the mixture of units of Continental and British derivation impairs efficiency. Similarly, there is nearly always the instrument which is due for a visit from the Service Engineer, and the inevitable cases where charts have not been changed for weeks or are missing altogether. On the other hand, there are cases where instruments are well maintained but whose readings are never consulted; the charts being stacked in neat but useless piles.

Often meters are recalibrated or repositioned without engineers or cost accountants being notified. It is not uncommon to find that an inferential type flowmeter has been moved from one position to another with no attention being paid to the basic calibration conditions of temperature, pressure and orifice to pipe ratio.

Most instruments by their vary nature are delicate machines. Frequently, however, they are required to operate under conditions of corrosion, vibration and heat or in dirty and humid atmospheres.

There is therefore, a strong need to provide a good maintenance service.

In the present context, the aim is to measure energy usage not only at the boiler or at the process plant but in terms of 'Energy per unit of production per unit of time' (145).

Lyle (6) stressed the need to adopt energy measurement relative to throughput of process material. Volume measurement is often convenient, but weight determination is the only satisfactory method. Even here product type, product volume and ambient temperature conditions will effect specific consumption. Other units for specific measurement include floor area, building volume, number of items produced or numbers of employees. Of course all must relate to some time scale.

It is possible to operate a boiler at 85% efficiency and still have a four fold increase in costs between energy as purchased and at its point of use. It is also true that distribution losses have a far greater effect on real energy costs at lower boiler efficiencies and that to rely on a figure of cost per thousand pounds weight at the boiler is superfluous. Table 4.8.1 demonstrates that measurement at the point of use is essential for good control.

The degree to which this is achieved will depend on financial feasibility. It must also be realised that the complexity of diffuse users would require a large number of meters for small flows. Numerosity may lead to adverse influence or accuracy.

In general, however, large firms in energy intensive industries should provide their specialist with more detailed measuring facilities,which can point the way to savings of small percentage but of large significant amount. Smaller less energy intensive firms require less sophisticated measuring devices, but the instrument provided should show the basic data upon which decisions can be taken. Diffuse industries may require a different approach. There is a prime requisit to survey the site, assess the important flows and parameter to be instrumented and to install automation for measurement and control. Even then, complexity will necessitate the adoption of alternative means such as remote sensing and statistical extrapolation.

4.8.2 The Ideal System

Many different processes demand a wide variety of data and it would be impossible to specify a rigid measurement system. Nevertheless the ideal system is so common in the use of fuel for transport that this analogy may show the way to effective design (4).

Industrial instrumentation often fails to measure primary requirements, meter reading is made difficult by design, or meters are widely distributed and often inaccessable. Is it too much to expect that plant be supplied with suitable instrumentation with centralised control, which will be maintained and used to ensure efficient operation of the factory?

Is it impossible to initiate agreed measurement systems and adoption of consistent units? For the moment it appears that industry must rely on the engineer specifying such instrument systems only to find that they have to be culled from the design to comply with the 'lowest tender syndrome'.

4.8.3 Automatic Measurement and Control

Automatic systems are designed to sense a predetermined condition, to institute remedial action and to collect informative data for management perusal. Systems involving the use of micro-processor and other similar sophisticated hardware are now available for control of individual plants, groups of plant, whole factories and groups of factories. Adoption by industry, mostly due to financial constraints, has, however, been slow.

Where systems have been installed, too often it is found that complete reliance is placed on unchecked automatic controls where creeping errors are allowed to be set up. Regular checking and calibration is paramount. It must be remembered that each control operation still depends on a measurement being taken, and such measurements depend upon instruments of increasing accuracy. This requires increasing care in choice, installation, maintenance and interpretation.

4.8.4 Indirect Measurement

One way of arriving at reliable figures for energy consumption is by direct measurement; i.e., the flow of steam to a piece of plant as measured by a meter. Such installation cannot always be justified. Consequently, alternatives need to be found. For example a practical way of arriving at a figure for steam consumption is to measure the condensate produced.

4.8.5 Specific Tests

Efficiency, wastage and losses from plant and equipment can be determined through specific measurement of the energy inputs and out puts to the operation. This approach signifies compound measurement instigated for a temporary one-off purpose. Derivation of boiler efficiency is a typical example.

TABLE : 4.8.1 - 'IN HOUSE INFLATION' (REF: 145)

Distribution and Process Losses as % of Purchased Heat Units.	Cost in Use of £1 Purchase Fuel B Boiler Efficiency %		
	70	80	85
10	1.67	1.43	1.33
15	1.82	1.54	1.43
20	2.00	1.67	1.54
25	2.22	1.82	1.67
30	2.50	2.00	1.82
35	2.86	2.22	2.00
40	3.34	2.50	2.22
45	4.00	2.86	2.50
50	5.00	3.34	2.86
55	6.70	4.00	3.34
60	10.00	5.00	4.00

Figure 4.9.1

Example of the Use of Matrix Analysis in Identifying Inefficiency

	Space Heating	Automatic Valve Operation	Automatic Flushing Toilets	Radiant Pannel Space Heaters	Feed Water Pump Drives	Cooling Drums
GAS						
OIL						
COAL						
ELECTRICITY	O	X			O	
TOWN WATER			O			O
BOREWELL WATER			X			
CIRCULATING WATER						X
STEAM				O	X	
HOT WATER	X			X		
HOT AIR	X					
HYDRAULICS						
COMPRESSED AIR		O				

O = Present energy source X = Proposed energy source

The procedures for determination of boiler thermal efficiency (6) (9) (147) or thermodynamic efficiencies of prime movers (148) (149) (150) are well established and require little elaboration here. It suffices to say that such tests are somewhat infrequent at Fort Dunlop; a situation which might well be reviewed.

Specific tests may of course be applied to the entire distribution network or specified sections. Measurement of the no-load consumption during an inactive production period will quantify total losses and overheads. Whilst this is possible for all common services such as steam, water, hydraulics and electricity, quantitative determination of total site and total department air losses is particularly suitable. Additional pinpointing of leaks from the distribution is also achieved through inspection during the quiet period. This is often impossible due to background noise during normal operations.

4.9. The Alternative Methods

4.9.1 Educated Guesswork

It is common practice to study areas of greatest use where potential savings may be largest.

Losses in a plant can often be assessed through educated guesswork exercised by an experienced and knowledgeable employee. Such a technique must not be underestimated. A multi-disciplinary approach could be beneficial.

Success may be achieved in a number of ways which involve no measurement The most obvious align with visual methods in association with some experience on behalf of the observer. Alternatively, examination of plant and equipment specifications in relation to operating requirements may identify misuse, examples include identification of existing motors and substituting with variable, load-following drives; or the substitution of electrically operated solenoid valves for compressed air actuators.

This procedure incorporates simple investigations into the type of system, its operation, and possible alternatives. A systematic approach, however, is important. Matrix analysis, of the type shown in Figure 4.9.1., will aid analysis.

There is also the educated guess based on past experience of plant operation and malfunction. This quality is expressed by many shop floor engineers, pipefitters and millwrights. Extraction of this information can often save much time and trouble at a later date.

4.9.2 Case Studies, Past Reports and Technological Advancement

In accordance with sound scientific approaches, reviews of past work, case studies and reports must surely form the point of commencement for any identification process. Re-investigation should not be dismissed as - 'not being feasible then so it is not worth looking at now'. Apart from alterations to economic bases, advancing technology induces continual updating of improvements in efficiency. Maintenance of effective communication channels for new discoveries, improved plant equipment and process modifications will provide a useful tool in identifying potential areas for action.

4.9.3 Visual

By far the most useful and yet obvious method is visual contact. This can either be simple or compound, ranging from direct viewing of a leak to detection of infra-red properties of hot spots using additional equipment. The success of interpretation of sightings and resultant identification will lie in the eye of the beholder. Experience counts for a great deal.

Simple visual identification is itself of two types: sightings of visible loss (i.e., Obvious steam or water losses, idle running of electrical equipment, lights left on etc.); and invisible loss (i.e., unlagged pipes, open windows, doors, vents and certain malfunctions of plant and equipment).

Of the visible means to identification are sighting of steam discharges. Leaks can be seen and very approximate estimates made for the degree of loss by 'length of jet' measurement. There are examples where some companies have developed a 'steam loss calculator' in the form of a slide rule; values being attributed to blow length.

The predominant difficulty facing improvements in maintenance and housekeeping lies in identification at the point of consumption. Here the system must rely on direct visual detection by the well informed employee. The problem becomes one of awareness, attitude and motivation.

In the hands of an experienced engineer, direct examination of equipment, plant or building behaviour may infer hidden losses.

Examples of this indirect technique are numerous and include:

- Continuous exhausted steam from condensate tanks and atmospheric exhaust pipes indicates passing steam traps.

- Warm drain water and/or steam emission from manhole covers depict excessive leakage of steam, condensate or hot water.

- Sightings of common bird/animal habitats show the warmer areas.

The compound method relies on the aid of some device to identify the loss. Like the simple methods, these can represent either direct or indirect identification. Infra-red technology for loss detection provides one example. Sophistication need not of course be carried this far: i.e., melting of snow on rooftops; photographs showing open windows, doors, running extractors or roof vents etc. The existence of such techniques hold potential significance. Further arguments are developed later in this and subsequent chapters.

4.9.4 Sensory Perception

Feel and touch offer another simple but effective procedure. Radiative heat is easily sensed at a distance. Surfaces too hot to touch (65°C) signify the need for lagging (3). Fluids which are hotter than expected depict either down-line loss and/or possibilities for heat exchange. The process is plainly obvious but the implementation often lacking.

As with visual techniques, physical sensing may be profitably extended to a higher level of sophistication through instrumentation. Temperature measurement is the simplest and gives good indication of the degree of heat loss. For absolute measurement of loss, however, indication of flow rate is also necessary.

4.9.5 Audile

Many leaks are often visible, physically sensed and audible. Other losses, may only induce sound. Steam leakage through a valve to a closed network of pipes is such an example. As for the two previous modes of identification, effective recording of losses depends greatly on the reaction of the shop-floor employee.

Measurement of sound, however, will not provide quantitive information on the extent of wastage, since the noise level produced will be a function of the orifice of escape as well as the flow rate, pressure and properties of the fluid.

Fluid flow through a constriction exhibits detectable ultrasonic noise emissions. Leaks and passing valves can, therefore, be identified using ultrasonic detection.

4.9.6 Indicators

Associated with visual identification, indicators, either specifically designed or inherent within the plant, can produce both qualitative and quantitative identification of losses. Section 4.9.3 has already mentioned the use of atmosphere exhausts from condensate collection tanks for detecting passing valves etc. In addition, many traps and valves are installed with atmospheric discharge valves (Figure 4.9.2). By shutting valve A and opening B live steam passing through the trap can be detected from the atmosphere exhaust. Alternatively a sight glass can be installed to give the same result.

Safety and bypass valves, level indicators etc., already designed into systems, will indicate excessive flows and pressures. Such conditions may be a product of energy wastage elsewhere (passing traps and valves) or malfunction of regulators and controllers (air main pressure controls locking open). These inbuilt indicators are of course numerous on large complex sites and already widely used by engineers.

Indicators, in particular alarms, may also be specifically designed. A most suitable example is the installation of electrical maximum demand alarms. When peak demands are anticipated by a pre-programmed monitor, alarms can be made to ring. Employees are then required to switch off pre-determined equipment until the level has subsided. This, however, relies on employee action which is not always forthcoming. A case can be made to install automatic computerised sequencial shutdown of electrical consumers (91).

Such items as carbon dioxide content, or more recently oxygen and/or carbon monoxide, and temperature of the flue gases from boilers or furnaces can be examined to indicate the level of efficiency of operation. Here, however, lie pitfalls. The use of such a technique, together with charts or slide rules supplied with combustion analysis kits, should be carried out with care. So long as it is appreciated that these measurements are a means of finding 'flue gas losses' and not 'true boiler efficiency', then the measurement can be valid; albeit that in the majority of situations indication of boiler efficiency is given.

Coloured or radioactive dyes hold important inference. The source of known downstream losses can be identified by injection of dye at various points further up. Such techniques have been used extensively

Figure 4.9.3

Identification Processes Relating to Activity Functions

Process	Consultants	Management	Foremen	Engineers Technologist	Operators	General Employees
Educated Guesswork	X			X		
Past Reports	X	X		X		
Visual:						
Simple	X	X	X	X	X	X
Compound	X			X		
Indirect	X		X	X		
Sensory	X	X	X	X	X	X
Audile;						
Simple	X	X	X	X	X	X
Compound	X	X	X	X	X	X
Indicators	X		X	X		
Measurement:						
Direct	X		X	X		
Indirect	X			X		
Specific Tests	X			X		
Accounting	X	X	X	X		
Statistical	X	X		X		
Analysis	X			X		
Work Study	X	X	X	X		

Figure 4.9.2

Layout of Steam Trap System

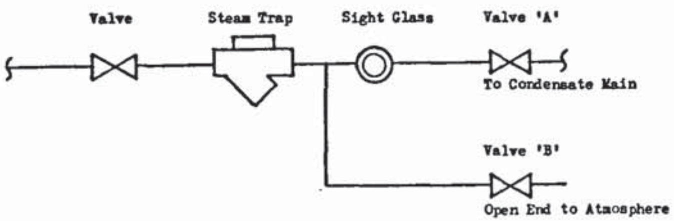


FIGURE : 4.9.4 - MEASUREMENT BY SENSING TECHNIQUES

ITEMS	SENSE	MEASUREMENTS
1. Unlagged Hot Surfaces -		
- Pipes	V - F	Length - diameter
- Flanges	V - F	Numbers - diameter
- Flat Surfaces	V - F	Area
- Domes		Area
2. Electricity		
- Lightsoon	V	Numbers - type
- Machines on	V	Numbers - type
3. Running Taps		
- Hot or Cold	V	Numbers - rough flow rate
4. Running Air Curtains	V	Numbers -
5. Leaks - Steam	V	Numbers - rough flow rate
- Air	A - F	Numbers - rough flow rate
- Water	V	Numbers - rough flow rate
6. Ventilation		
- Windows	V	Numbers - type
- Doors	V	Numbers - type
- Gaps	V	Numbers - area
- Vents	V	Numbers - diameter
- Extractors	V	Numbers - diameter - speed

NOTE: All are relative to a time scale.

Visual = V
Audible = A
Feel = F

MFG/AW/1.2.79

at Fort Dunlop to determine actual flow patterns of hot and cold water and their cross migration from one closed system to another. Dye-flow analysis is purely qualitative; additional measurement is required to determine quantitative loss.

Associated with this technique is analysis using heat indicator paint. Stemming from identification of heat distribution in gas turbines, application of temperature sensitive paint or wax to specific plant and equipment, (i.e., before and after steam traps) signifies untapped potential in the detection process.

All measuring instruments are intrinsically indicators. Some actually reflect the physical condition whilst others infer a situation elsewhere. The mode of communication is either simple, relying mostly on the visual and audile senses, or compound, involving automatic data gathering and some degree of computation.

4.9.7 Summarising Comment

The process of detection of energy usage is progressive. Simple sensing gives way to instrumentation and automatic measurement. The degree of sophistication will reflect the factory environment and the need for effective identification. For diffuse industries, the problems are clear. There is a need to improve existing techniques and develop suitable alternatives.

The solutions to the difficulties appear numerous, varying from simple sightings to complex metering and analysis. Amongst the possibilities are one or two new procedures such as infrared analysis. Development of these ensues in forthcoming discussion, but already it becomes evident that each are complimentary and that no single method will predominate independently. Figure 4.9.3 summarises the potential identification processes as related to various activity functions.

4.9.8 <u>Sensing Techniques</u>

To most, the use of the senses is too obvious to be used as suitable techniques for assessing the use or misuse of energy. For example: unlagged pipework carrying a hot fluid can be seen, the lengths, diameters and temperatures measured, and the corresponding heat loss calculated. The general attitude of employees, however, is to the contrary. Instead of assessing the loss and initiating action, the attitude is to simply avoid touching the hot surface,or more commonly to ignore the loss completely. Pipes too hot to touch should be lagged.

The methods of visual, audile and sensing by feel require nothing more than the counting of numbers, simple measurement and basic computation using pre-calculating data in tabular form. Figure 4.9.4 indicates the extensive application of this technique. So as to minimise the time taken for a survey, tables of the costs and uses of energy losses were drawn up for Fort Dunlop, (a list is given in table 4.9.5.) Primarily this was produced for the 'Results' package a practical 'Spot the Losses' awareness exercise designed for the training programme (326) (327). Later these were extended to a form which could be used for detecting the use and misuse of energy. (324) (325).

The aim of the tables was to provide a means of attaching approximate values of cost and consumptions to observations based on nothing more than simple sensing. It was essential that the tables could be used

TABLE : 4.9.5

List of Tabular Data for Sensing Techniques - Ref: (324) (325)

a) Electricity
- Use
- Lighting
- Process Machine

b) Oil Use

c) Gas Use

d) Steam
- Leaks
- Flash Collection
- Condensate Collection

e) Water
- Process hot water use
- Domestic hot water use
- Process cooking water use
- Domestic cold water use

f) Air Leaks

g) Heat Loss
- For Pipes
- For Flanges
- For Flat Surfaces
- For Domes

h) Space Heating Losses
- For Air Curtains
- For Windows, Doors & Gaps
- For Roof Extractors
- For Roof Vents

M F GRAY

MFG/AW/1.2.79

TABLE : 4.9.6 - NON-LOAD COMPRESSED AIR TEST - FORT DUNLOP

DEPARTMENT	LOSSES	AVERAGE * CONSUMPTION 1975	PERCENTAGE LOSS	+ COST OF LOSSES AT 1975 PRICES
	M3/hr	M3/hr	%	£
Factory Total :	10,188	23895	43	70,000
Tubes	2,547	3469	73	17,000
Tyre 4	849	4406	19	6,000
C.P.D.	1,019	1914	53	7,500
Tyre 1	1,019	-	-	7,500
Curing Bag	849	-	-	6,000
F.P.D.	349	491	71	2,500
Tyre 6	509	1083	47	3,500
Tyre 2	1,189	4522	26	8,000
Tyre 7	340	-	-	2,500
Tyre 5	679	-	-	5,000

ADDITIONAL INFORMATION

Air Supply Pressure - 120 psig

No load was required for production or engineering purposes.

+ Costs based on electricity costs only

* Average consumptions for 1975 based on 5000 hours production during the year.

MFG/AW/1.2.79

and understood, without difficulty, by any employee. To date, however, verification of this means of detection remains largely unproven since only one trial, carried out by a production foreman, has been attempted (153). Future work will necessitate actual measurements of consumption of energy for comparison with the approximation arrived at by simple sensing.

The majority of sensing techniques are based on visual identification. It is possible, therefore, by means of photography to produce a permanent record of any investigation carried out. Studies of the photographs, assessment of losses and computation of costs can then be carried out at leisure. A number of such exercises were carried out at Fort Dunlop, the results of one of which are given below:

<u>Example of Photographic Sensing of Energy</u>   <u>Date 14.7.78</u>

Time: 15.30 hours   Photographs - Plate 4.A

Ambient Temperature : $19^{o}C$

Internal building temperature in Tyre 1 = approx. $24^{o}C$

Internal building temperature in Curing Bag Dept. = approx. $40^{o}C$

Costs based on 1975 data.

<u>Photograph 1</u> "Unlagged flanges, valve and pipework"

Fluid = Steam - 310 psig main (21.4 bar)

Pipe and Flange size = 1 inch NB (2.54 cm)

Number of flanges = 2

Length of pipe in picture = approx. 2 m (6.5 ft)

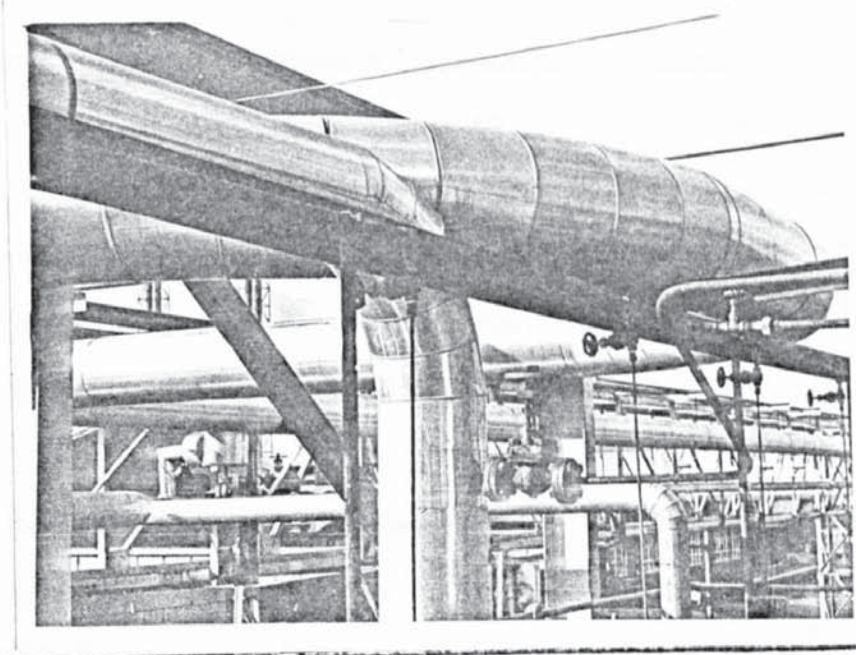
Surface area of valve = approx. $0.15m^2$ ($1.6 ft^2$)

From tables (324) (325) avoidable heat loss:

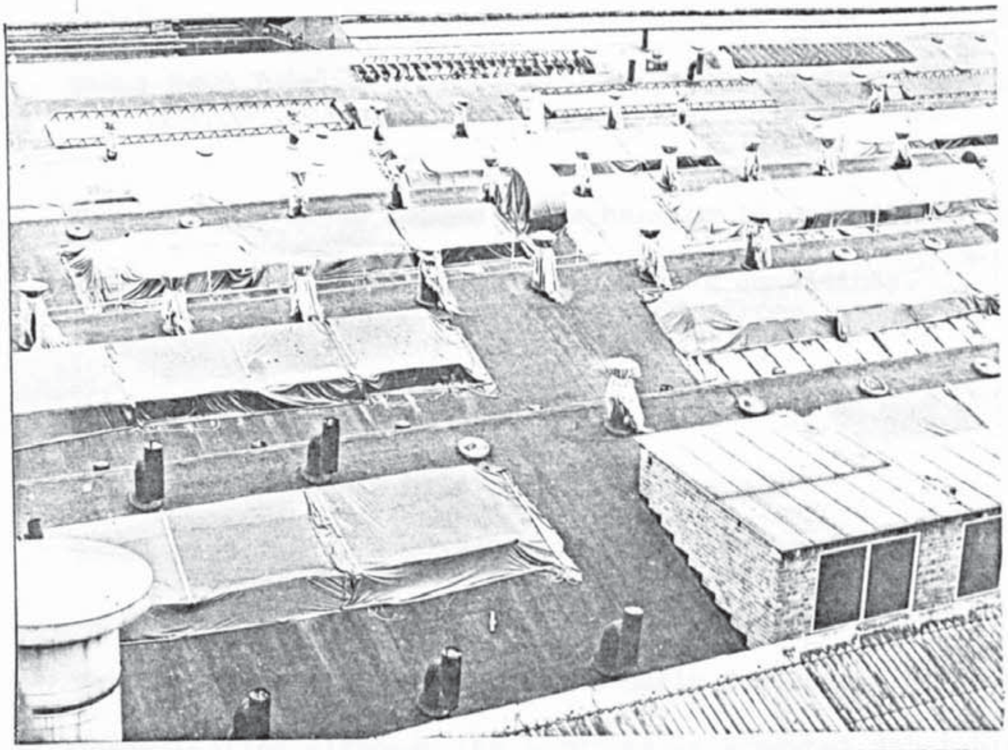
-	from flanges	=	7000 MJ.pa	=	£ 8.80 p.a.
-	from pipework	=	22790 MJ.pa	=	£ 28.60 p.a.
-	from valve (estimate)	=	8160 MJ.pa	=	£ 10.30 p.a.
-	Total heat loss	=	37950 MJ.pa	=	£ 47.70 p.a.

PLATE 4 A

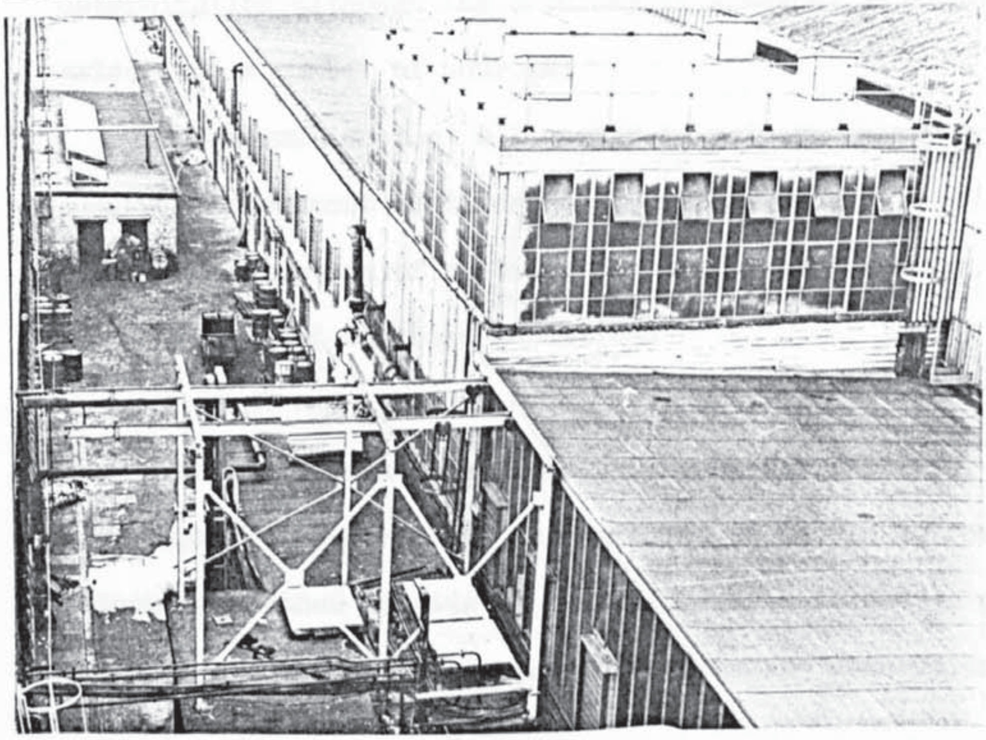
1.



2.



3.



Photograph 2 "Tyre 1 roof vents and Curing Bag louvres"

Number of roof vents (Tyre 1)	= 7	(natural draught)	
Diameter of vents	= approx. 0.23m	(9 inch)	
Cross sectional area	= approx. $0.009m^2$	($0.1 ft^2$)	
Total area	= approx. $0.063m^2$	($0.7 ft^2$)	
Total heat loss	= 600 MJ.pa	= £42 p.a.	

Number of louvres (Curing bag)	= 2	
Area of louvres	= approx $16.7m^2$	($180 ft^2$)
Total area	= approx $33.4m^2$	($360 ft^2$)
Total heat loss	= 310000 MJ.pa	= £19440 p.a.

Note: These costs assume space heating is provided by "primary energy input" and not "waste heat", and winter conditions.

Photograph 3 "Steam leak Tyre 6"

Condition - small hole : fine jet

Total heat loss = 123000 MJ.pa = £100 p.a.

The technique clearly provides a basic assessment of energy loss determination, although the accuracy is somewhat debatable. Error can arise from a number of sources:

- assumption that all energy is primary energy input
- assessment of dimensions, temperatures
- assumption of specific flows of energy through a point
- assumed standard conditions

Such errors are even more pronounced when the basis for assessment is a photograph. For example the employee is unable to feel a pipe to determine whether lagging is required, he is forced to guess dimensions from the picture and he is pushed into making assumptions concerning conditions. So whilst this method has some validity, particularly, in creating awareness, by itself it is not sufficiently accurate to determine a total loss account.

4.9.9 No-load Compressed Air Test

Energy loss, whether it be steam, compressed air or any fluid, will accrue through pressure drop in piping distribution, leaks or, as in the case of thermal fluids, radiation and convective heat loss. Amongst others, one way of accurately assessing the percentage loss due to air leakage is to charge the system with compressed air during a period when there are no production load requirements and to measure the rate of flow at specific points. Such a test was carried out at Fort Dunlop in June 1977 the results of which are given in Table 4.9.6.

It is believed that the measurements taken, the computation and the results obtained reflect a reasonable level of accuracy, thus validating the method as a useful tool in assessing the performance of compressed air usage. It can be reasonably assumed that meter error is unimportant since the objective is to ascertain percentage loss, the errors thus being cancelled out.

In totality, however, the test failed to take advantage of the full potential of the exercise. Once a rate of loss had been identified it would have been astute to investigate each department in turn, each audible leak being identified and reported. This was not carried out and hence the opportunity to pinpoint each loss was wasted.

4.9.10 Steam Consumption by Condensate Measurement

Where steam is used inside a heating surface, the amount of condensate produced is a measure of the steam used. Instrumentation requirements are simply a measurement vessel and stop watch.

The trap outlet, disconnected from the condensate main, is discharged either direct into a collecting vessel, or into a vessel containing cooler water, or through a cooling system into the vessel. Whichever the system used, the vessel must be weighed before and after the expériment. Should the discharge uncooled to the vessel be direct, compensation for flash steam loss must be made in the calculation.

If the heating surface is well drained, if the trap is in good order and if the condensate collection is well arranged, the steam will give up its latent heat only, and the condensate will be discharged with all its sensible heat. In reality this is seldom so. Faulty, traps, faulty condensate draining, cracked open valves can cause two faults:

a. condensate can be held back in the heating surface so that it waterlogs the surface and slows down heating while it parts with some of its sensible heat;

b. steam can pass in additiun to condensate.

It is of course possible to combine steam metering and calorimetry by condensing flash and live steam, plus the condensate collected into cooled water contained in the vessel. The temperature of the water compared with the amount of condensate will give the real picture. In practice this is difficult to apply for obvious reasons of heat loss and the corrections for heat capacity of the vessel.

Even when all corrections have been made there is still the assumption that the input steam is dry saturated. To get any accuracy at all by weighing or measuring condensate, the quality of the input steam must be measured. However, the procedure has obvious application. Several experiments carried out in recent years at Fort Dunlop have produced encouraging results. These are described in Appendix I.

4.9.11 Identifying Leaks by Measurement of Ultrasonic Vibration

In all areas using steam, compressed air, hydraulics and water there is plant and equipment, such as valves and steam traps, which cannot easily be checked for internal leaks. Valves or traps passing steam, while in a closed position, can give massive wastages which remain undetected for long periods. Drain and exhaust valves on pressed are especially critical. (87). In order to try to detect passing steam easily G. Fradgley set up a number of trials in Tyre 4 and Tyre 2.

Upon investigation it was found that there were two alternatives for detecting passing steam, both of which made use of sonic properties. The first of these involved the use of a doctor's surgical stethoscope, thought to be rather fragile though not completely out of the question. The second incorporated operation of a Sykes - Pickavant sonascope, an industrial/surgical type instrument.

Theoretically the only problems expected were extraneous noises from outside the pipes or transmitted through the pipes. In practice, stethoscopes tended to be impractical for additional reasons, such as difficulties encountered in physical attachment. Consequently, G. Fradgley concluded that only sight-glasses, or the fitting of atmosphere valves, could be accredited any degree of success in identifying passing valves and traps.

Since that time, however, progressive thinking led to incorporating ultrasonic detection, thus eliminating much of the audible background noise. Investigations led to trials carried out during 1977-1978 using a Dawe Ultrasonic Leak Detector on a variety of valves on traps. This proved more successful.

The basic application for this instrument is to detect fluid leaks, either gaseous or liquid from vessels, pipes etc. which contain the fluid under pressure, or through valves and traps already within the pipe network. Fluid, in particular gas, escaping through a small orifice produces a wide band noise in the upper audio and ultrasonic frequencies. In several cases leaks can be detected directly by the hissing sound produced.

However, using ultrasonics, the scope of leak detection is greatly enhanced both through sensitivity and directional discrimination. The microphone and amplifier are tuned to record only a narrow band of ultrasonic frequencies, thus removing masking audio frequency sounds in generally noisy surroundings. Figure 4.9.7 shows a diagrammatic layout of the instrument.

The ultrasonic noise generated by a gas leak depends not only on the gas pressure and escape velocity but also on the physical characteristics

FIGURE 4.9.7 Ultrasonic Leak Detector - Schematic Drawing

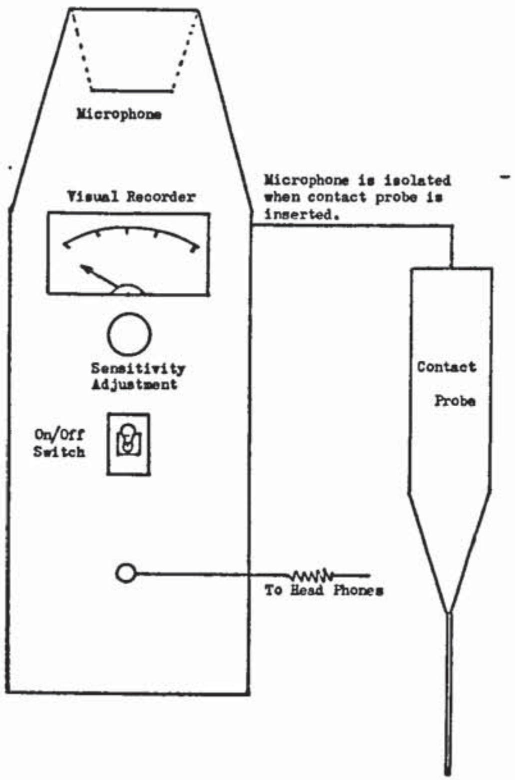


TABLE: 4.9.8

Investigation of Steam Trapping - Tyre 5 Moulding

DATE: 10th November 1978.

The following conclusions resulted from a survey of steam traps in the Tyre 5 Moulding area using a Dawe 8902A Vetiosonic Leak Detector. Traps tested and not functioning correctly were marked with a white wax.

	Passing Traps	Total No. Of Traps Tested	Position
'A' Line			
Subway -	9	51	
(Note a previous survey on 13.6.78 indicated 14 traps passing)			
'B' Line			
Presses -	1	3	B1
	0	6	B2
	0	6	B3
(Further investigation is required).			
'C' Line			
Presses -	4	5	C1
	5	5	C2
	2	3	C3
	1	2	C4
	3	3	C5
	2	3	C6
	1	3	C12
(Of the above presses tested, 18 out of 24 traps were passing (75%). It is recommended that all traps be changed or refurbished).			
'D' Line			
Subway -	3	10	
Presses -	2	3	D3
	1	3	D6
(10 presses were checked, each having 3 traps).			

COMMENT

Of the total number of 130 traps, 34 were passing (26%). Approximately 75 traps have not been tested on A, B & C presses.

Steam trapping is a problem. TD traps appear to be somewhat unsatisfactory from the point of view of life before malfunction and excessive steam leakage with discharge. Two recommendations can, therefore, be made:-

(a) Assessment of operating performance should be carried out for a variety of traps to determine the suitability of a particular trap in the required conditions.

(b) Investigation of a planned schedule for steam trap maintenance throughout the site.

of the hole. The shape of the hole, its surface roughness and the sharpness of the edges all have a major effect on the noise level. For these reasons, there can be no reliable correlation between the instrument sensitivity quoted on standard holes and the true practical sensitivity.

As an indication of sensitivity of the Dawe 8902A detector, detection of an air leak of 3cc/min. at a pressure of 30 kgf/cm^2 is claimed.

Using the microphone, without the contact probe connected, the general background noise level in the moulding areas of Tyre 5 was assessed. With this in mind the probe connection was then inserted and the probe itself placed on the upstream section of the steam trap being examined. The sensitivity was then adjusted to a suitable level. This, along with the converted ultrasonic noise now audible through the headphones, was noted before repeating the procedure on the downstream section. On each occasion, a reasonable time period was allowed to permit a complete discharge cycle of the trap to be made.

Passing steam produced increased ultrasonic emission. Continuous noise indicated a passing trap; no noise inferred a seizure. A fully functional trap produced a variation in sound level as the cycles progressed. The results of the investigation are given in Table 4.9.8.

The technique undoubtably demonstrated its effectiveness for detecting passing steam traps. Each trap found to be faulty was stripped down and the diagnosis confirmed. Certain difficulties, however, did present themselves. Equipment having a severe steam leak to atmosphere elevated background noise to such a level that it was difficult to assess the trap performance. Moving the probe from upstream to downstream helped to overcome the problem. Secondly, most installations incorporated a variety of trap types, each having their own performance characteristics and cycle times. It was, therefore, necessary to have some knowledge of the trap being studied along with details of the steam condition, process operation and plant performance.

Generally, the method, proved simple, easy to carry out, reliable and effective. In addition to steam traps, investigation of various valves on steam, air and hydraulic services was possible. With the equipment being relatively cheap, the technique was demonstrated and recommended to the entire Dunlop UKTD.

For sites the size of Fort Dunlop, the number of traps and valves used on the plant must number several thousand. Avoidable losses through malfunction are enormous. It is, therefore, imperative that a regular planned maintenance programme be initiated. Savings in excess of 10% are achievable. Many of these traps and valves, however, are in trenches, behind machines, on overhead pipeworks etc. Accessability and numerity present a problem. It is envisaged that specific personnel, conversant with the operation of this detector, will need to be appointed on a full time basis if full advantage is to be taken. Similarly, once the malfunction has been identified, it is a must that management commitment be sufficient to get the job done.

CHAPTER V

STATISTICAL ANALYSIS TECHNIQUES FOR IDENTIFYING ENERGY LOSS AND INEFFICIENCY

5.1 Chapter Preview

Identifying energy wastage, assessing energy performance efficiency, and controlling energy usage in 'diffuse' industrial operations is far from satisfactory. Previous chapters have reasoned the inconsistancies in this sector of British Industry; the major difficulty being one of identifying the energy flows and losses under the normal constraints of economy and policy.

Excessive metering of every energy flow is not only unjustifiable economically, but in the light of discussions in Chapter 4, altogether impractical. Chapter 4 also spelt out the alternative means of identification. Amongst others it reviewed the possibility of adopting statistical techniques in determining where, how and at what level energy was being wasted. This chapter extends this discussion. Both simple statistical theory on pro-rata probability and regression analysis are considered. Finally, the results of the Fort Dunlop data processing exercises are given together with the formulation of the energy consumption model for this site.

5.2 Statistical Theory in Energy Analysis

Energy usage is probably influenced by many things, and it is more than likely that these variables will not be independent. For example, according to O. Lyle (6) and P. Lyle (141) energy can be related to production output. At Fort Dunlop, production activity has been used for a number of years to assess specific energy performance. Reductions in production output, however, tends to be accompanied by increases in specific usage. The assumption that this is a suitable measure of performance is, therefore, false.

If all the factors controlling energy consumption were known, it would then be possible to form systematic procedures for identification. At present, it would appear that investigations are based as much on pure guesswork as on actual facts. Often savings cannot be identified in the energy bill, since they are lost in the overall consumption pattern.

Influential factors need to be identified and meaningful relationships with consumption derived. Regression analysis of existing statistics, assuming the original data to be suitably accurate, provided one vehicle for achieving this. The ensuing models can then be built into the normal accounting system to give comparison of actual efficiency with budgets and targets; the deviation from the normal being identified.

Engineers are often asked to assess the energy losses on a site and to indicate the potential for conservation. To carry out detail measurements or surveys on a diffuse site is uneconomical, time consuming and impractical. One way of arriving at an estimate is to select one area or department known to be inefficient, carry out a reasonably detailed survey involving some measurements, and to extrapolate the findings to the entire site using the standard statistical theories of probability.

5.2.1 Control of Energy Costs

Typical problems arising in industrial cost accounting are that energy usage figures cannot be disaggregated adequately from an overall global figure. All too often energy expended in producing a product through a multitude of processes becomes hidden in a morass of assumptions and contradictions. The problem involved in assembling suitable data is that it cannot be considered in isolation for the purposes to which the data is to be put.

Control suggests comparison between actual energy consumption and some predetermined standard. To do this energy costs must first be subdivided and examined to see on what they depend. For example many factories treat energy costs incurred on production, space heating, internal transport etc. as one entity, irrespective of what fuel source is being used and for what purpose energy cost is being incurred. Such a control system is likely to be meaningless; production energy will vary with output, space heating with ambient temperature, transport with mileage etc. Simply to take global figures for comparison, without considering the purpose of its incurrence, only indicates that the behaviour of energy has not been understood.

It is, therefore, imperative to subdivide energy costs incurred into sources (gas/oil, electricity, steam etc.) and to subdivide each source into its use or functional production area (37). The heat incurred in vulcanising rubber may depend as much on ambient temperature and curing cycle time as on tyre weight; whereas the electricity used in masticating rubber in a mill might vary with tonnage of rubber and its physical properties.

Within 'diffuse' users, infinite subdivision into energy source and consumption point is not plausible. Instead there is need to begin at the other end by identifying major energy sources and those factors which influence site consumption; only after which further segregation into activities might be considered.

5.2.2 Control Models and Budgeting

All too often in practice, a budgetary figure for energy use is selected on the basis of production output targets, and thereafter by predetermined ratios or arbitrary variables at each production state. Quite apart from the inaccuracy of the ratios etc., budgetary control does not easily identify the energy costs/consumptions that are incurred when achieved output fails to reach target. In addition, rarely do cost accounts build in budget flexibility to allow for variation in uncontrollable factors such as ambient temperature.

A departmental manager can hardly be held responsible for adverse variances from budget simply because the weather has turned colder or planners have altered his production output level for that month. Budgets should, therefore, be flexed to account for these. It is not advocated that these factors be removed from the energy performance calculation and thereafter ignored. Rather it is suggested that such a model aspires to informing the departmental manager the reasons for any variation in energy usage, whether this be due to production level, ambient temperature, bad housekeeping or plant failure.

At Fort Dunlop, it is reasonable to assume that budgetary control of energy cost/consumption is unlikely to be suitably effective. It is not suggested that regression analysis is the perfect or the only method, but that it can be simple, unbiased and flexible and meets some of the outstanding requisits.

5.3 Statistical Theory in Pro-rata Energy Loss Evaluation

It can be argued that certain types of wastage such as passing steam traps or valves, steam and air leaks, tyre presses being left open; or machines and lights being left on is common throughout most parts of a large site the size of Fort Dunlop. To investigate each and every building, machine or operation would take too long. The alternative is to study a specific area, selected at random, and extrapolate the results to include the whole site. It is important, however, to ascertain the degree of certainty to which the global figures can be believed. Statistical theory provides such a measurement.

The use of the theory of statistics can be introduced by the concept of probability. If, for example, the proportion 'p' of defective steam traps in a tested batch is known, it is possible to estimate:

a. the number of defective traps throughout the site using pro-rata extrapolation;

b. the probability of success, or failure, in discovering a faulty trap in a specific number of inspections carried out elsewhere;

c. the probability that a batch somewhere else in the plant is acceptable, based on a random sample taken from it.

With most statistical theory, it is always easier to comprehend through the use of examples. For the purpose of this exercise, the study of steam traps has been selected.

Steam traps on a site the size and complexity of Fort Dunlop, are numerous, vastly varying in type, often inaccessible, and consequently rarely checked for effective operation. Even with the relative ease of inspection using devices such as an ultrasonic detector, numbers and accessibility is still a problem. Taking the findings of the Tyre 5 steam trap investigation (Chapter IV) as the basis for appropriation, an estimate of the probability of the number of passing traps on the site, and the probability of detecting them can be established.

5.3.1 <u>Pro-rata Extrapolation</u>

Assuming the results of the investigation to be accurate, it is now possible to estimate the total number of faulty traps for a number of areas. The results are given in Tables 5.3.1 to 5.3.3.

Having obtained the number of traps passing steam, the next step relies on assignment of some value to the actual steam lost. In

TABLE 5.3.1

Actual Results of Steam Trap Investigation – Tyre 5

	Passing Traps	Total No. Tested	Proportion Faulty (%)	Total No. of Traps
'A' line presses	9	51	17.6	51
'B' line presses	1	15	6.7	63
'C' line presses	18	24	75.0	51
'D' line presses	6	40	15.0	40
Totals Moulding	34	130	26.2	205

TABLE 5.3.2

Extrapolated Results from Steam Trap Investigation – Tyre 5

	Total No. of Traps	Proportion Faulty (%)	Estimated No. Passing
'A' line presses	51	17.6	9
'B' line presses	63	6.7	4
'C' line presses	51	75.0	38
'D' line presses	40	15.0	6
Totals Moulding	205	27.8	57
Tyre 1-3-5 Totals (estimate)	307	27.8	85

TABLE 5.3.3
Extrapolated Results for Tyre 1-3-5, Other Departments and Site Totals

	Steam Consumption 10^6kg (1977)	Estimated No. of Traps	Estimated No. Passing
Tyre 1-3-5	81.3	307	85
Tyre 2	70.8	267	74
Tyre 4	97.6	369	103
Tyre 6	67.9	256	71
Tubes	30.7	116	32
C.P.D.	27.1	102	28
F.P.D.	32.9	124	34
Total Production	408.3	1541	427
Total Site	515.3	1946	541

Proportion of faulty traps = 27.8%

practice this is difficult since the loss will depend on the site and type of the trap (68), the steam pressure and the pressure at the trap discharge. In addition some useful heat will be recovered from higher condensate and pipe temperature respectively returning to the boiler and radiating within buildings. Much of the steam in condensate mains, however, does not condense and is discharged to atmosphere at pumping trap points and collection tanks.

Even if it is assumed that all faulty traps pass a similar quantity of steam, the accuracy of the overall assessment still relies on the degree of certainty in extrapolation. For example, when considering a single line of presses, such as 'c' line -Tyre 5, it can be said that the proportion of faulty traps (75%), which were proved by testing, would be the same for the remaining half of the presses not tested; most of the traps being of similar type and operating under common conditions.

When considering the total number of traps in Tyre 1-3-5, or throughout the site, the estimation error grows. Firstly the calculation of the number of traps is based on steam consumption; a gross assumption. Secondly it is assumed that the types of trap losses are similar. Consequently the compound error, will be large. At best,the ascertaining of a value for the loss is more by luck than judgement. Bearing in mind that losses from plant occur as much from radiation, convection and conduction as from leaks, passing valves, and faulty traps, together with variance in the heat content of steam (2952 kJ/kg for high pressure steam discharging direct to atmosphere, to 2346 kJ/kg for low pressure steam discharging into a condensate main) a conservative estimate for losses through a passing trap is put at 124000 MJ/year (at 1977 prices = £200 /yr).

5.3.2 Probability

Once the number of faulty traps have been ascertained and the assumption made that the remainder are similar, it is important to assess the probability of this being a meaningful value. This can be found from the Binomial Distribution (142).

$$P(r) = {}^{n}C_{r}\, p^{r}\, (1-p)^{n-r} \quad (\text{for } r = 0, 1, \text{----}n)$$

Where: 'n' = number of trials, 'p' = probability of success, (1-p)= probability of failure, and P(r) is the probability of getting r successes from n trials.

Based on the concept of the "Kill Ratio" (142), the chance of finding a faulty trap on C line in Tyre 5 is 0.75. If it is assumed that there are on average 3 traps per press then the probability of not finding at least one trap passing on that press is $(1-p)^{n}$ (the "Miss Ratio"):

$$(0.25)^{3} = 0.0156$$

Similarly assuming the probability of finding no passing traps is 0.25, the number of tests 'n' which would have to be carried out in a department such as Tyre 5, to have a 95 percent probability of assuring efficient trap operation can be calculated.

The probability that a passing trap is found is given by $(1-p)^{n}$ = 0.75^{n}. Hence the probability that the traps are functioning = $1-0.75^{n}$. But this must be greater than 0.95.

Hence $1-0.75^{n} \geqslant 0.95$

giving n = 11 since n must be an integer.

This means that if elevan tests are carried out on 'c' line presses without the discovery of a faulty trap, it can be said with 95 percent certainty that the remainder of the traps will be functioning correctly. The probability distribution can also be found for any number of tests from the formula:

$$P(r) = {}^{11}Cr(0.25)^r(0.75)^{11-r} \text{(for } r = 0 \text{ to } 11)$$

The 'inspection ratio' enables a random sample of item (i.e. n), taken from a very large batch, to be tested for defects, which if found the total batch is rejected. Thus P(p defectives) = $(1-p)^n$ = probability that a batch is accepted. When p=0 the batch can be accepted: when p=1 the batch must be rejected. For intermediate values of p, the expression $(1-p)^n$ must be evaluated. The results can be plotted on a graph as shown in Figure 5.3.4. It shows that for a sample size of n=5, with the exception of 'B' line, the degree of certainty that a complete line of presses is accepted as having functional traps is small.

5.3.3 Comment

Pro-rata energy loss evaluation can provide little more than a feeling for the quantity of energy being lost in a diffuse factory. Even linked with statistical and probability theory, little certainty can be placed on identifying the degree of loss, primarily due to the difficulty in associating a value with the loss and, perhaps more astutely, to the shortcomings of the analysis. To have any meaning at all, random selection of items from an infinitely large batch must result. In practice this is not possible.

A second difficulty lies with dependence and numerity of variables. It is questionable whether each result obtained is mutually independent. For example it could be said that the length of time a trap has been installed, the number of cycles it has undergone, and the conditions under which it has operated could not only influence the probability that it will be found to be passing, but could also indicate the likelihood that other traps under similar conditions would do the same. Finally the type, make and size of trap, the conditions for which it is installed, and the operation of the process will also exhibit influence. These parameters are known to vary throughout the Fort Dunlop site. It is, therefore, difficult to attain much conviction from results of this type.

Restricted to specific areas under uniform conditions, it is possible to evaluate the following with some degree of certainty:

a. The probability a test would find the trap to be passing

b. The number of tests which would have to be made in order to assure all the traps are functioning correctly.

c. The probability of acceptance of the batch based on a sample.

d. The probability of a trap passing after it has been installed for a specific length of time.

This last point forms the basis for future work. For any one area, having similar conditions, a series of tests on traps can be carried out to a scheduled timetable so as to produce a distribution curve, from which the probability of malfunction and hence the optimum timing of replacement can be assessed for a planned maintenance schedule.

The procedure described in this section is equally applicable to diaphram valves on steam, air or hydraulic controls, thermostats,

Figure 5.3.4
Probability that a batch of traps on Tyre 5 press lines is accepted

Press Line	Fraction Faulty	No. of Traps	Sample Size	P(o)
A	0.176	51	5	0.380
B	0.067	63	5	0.707
C	0.750	51	5	0.001
D	0.150	40	5	0.444

Where P(o) = the probability of no defectives being found
$= (1 - p)^5$

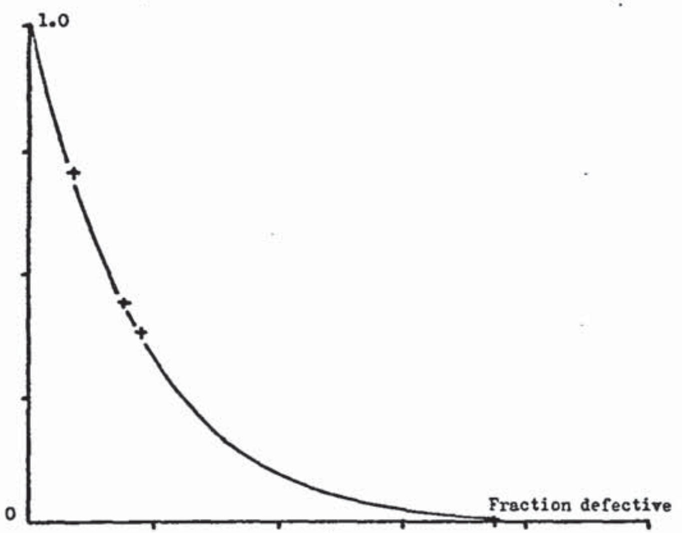


Figure 5.4.1 Production Output vs. Steam Consumed

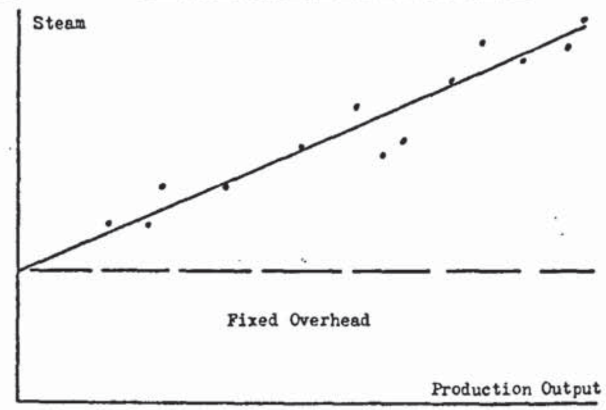


Table 5.4.2 Significance Levels

(Fisher & Yates - Statistical Tables)

Number of Points (N)	Minimum value of correlation coef. (R) such that odds are 100 to 1 against the relationship being due to pure chance.
10	0.767
15	0.641
20	0.561
25	0.506
30	0.464
35	0.425
40	0.402
45	0.380
50	0.362

metering systems, etc. Total losses might also be assessed and extrapolated on the basis of specific measurement:

a. floor area - lighting left on

b. building volume/roof area - ventilation/radiation losses

c. product output - moulding radiation loss

d. manhours - idle running machinery

e. employees - wasted water consumption in washing and toilet facilities

Alone, however, statistical postulation based on a number of actual measurements, does not effectively reduce the identification problem. Additional information is still required.

5.4 Regression Theory

Mostly, energy consumption varies with output, weekly and monthly comparisons being made on a unit output basis. Consumption per unit output, however, may only be done for a limited range since this too can vary with output. Commonly, specific energy usage declines with rising output, thus making weekly comparisons somewhat dubious if output levels are not identical.

The prime objective of energy analysis is to prove an accurate and meaningful assessment of performance. The present Fort Dunlop system of monitoring, charting and distributing information on specific energy use in departments etc. is inadequate for purposes of comparison and does not identify inefficiency.

Scatter diagrams - statistical analysis of best fit using the method of least squares - regression analysis etc. have all been used before (6) (141). Many managers, however, have fought shy of their adoption or, where they have been used, questioned the validity of the results. For energy and identification of its misuse, the results might not prove quite so incredulous.

5.4.1 The Regression Equation

Assuming a straight line can be drawn through a scatter diagram comprising of plots of say steam consumption vs production output, and that the line is representative of the relationship between steam used and output, then the dependence of one variable on the other can be given by: (See figure 5.4.1)

$$Y' = a + b, X$$

where: Y' = estimated steam consumption/week (in kg.)

a = the fixed consumption regardless of output (or analogous to cost accounting 'overhead')

b = the marginal consumption per kg of output

X = weekly output

Of course the equation need not be confined to linear equations; polynonials of any order can be used albeit with increasing complexity and often at the expense of declining credibility.

The method of least squares, as explained by most statistics texts, (141) (142) provides a means of assessing mean values, thus giving the best fit and a way of measuring the deviation from the real value.

The best value of b is when the 'Correlation Coefficient' between x and e = 0 (where e = error)

i.e. $b = \frac{Syx}{Sx^2}$

This is the 'Regression Coefficient' and is the gradient of the line.

5.4.3 Correlation and Significance

The apparent relationships may be as much due to chance as to any real relation. The worth or value we can assign to a regression equation can be found by finding the 'Correlation Coefficient' and testing the 'Significance'. The 'Correlation Coefficient' (r) is a fraction, the square of which indicates the proportion of true relation that the equation represents, the remainder being due to chance or error. A value of $r^2 = 0.85$ indicates that of the total variation in steam consumption, 85% is due to change in output and 15% to other causes including error.

In making tests of significance, the objective is to decide whether to accept the regression equation or to reject it because the test has shown that the correlation found may easily have arisen by pure chance when there was really no correlation between the variates. If, for example, there are too few points, even with a correlation coefficient of 1.0, the result may be worthless. The fewer the points, the less the significance. However, it is not necessary to go to significance levels which are too high. The Fisher and Yates Statistical Tables indicate the significance levels in Table 5.4.2 for odds of 100 to 1 against the relationship being due to chance.

5.4.4 Interpretation of Results

O. Lyle (6) demonstrated that it was possible to identify improvements using regression techniques (figure 5.4.3). However, he voices two notes of caution. For reliability, as large a variation in output and as many scatter points as possible are required. For this reason, figures should be taken out weekly rather than monthly. Weekly figures are, however, less reliable than monthly data due to accounting variations. Monthly figures tend to smooth out anomalies.

Correlation and significance provides a degree of confidence. They do not, however, tell how accurate the equation will be in forecasting the future. It is necessary to determine the degree of trust that can be placed on the value of the position and slope of a line; 'fiducial limits' are used to this end (Figure 5.4.4).

5.4.5 Multiple Regression

So far it has been assumed that a particular variable is dependent only on one factor (i.e. output). In reality, it is usual to find that the scatter of points is such that there is strong probability of there being some other influential factor, completely independent of the first (i.e. ambient temperature). Multiple Regression provides a suitable mechanism for achieving correlation between a selected item and a number of completely independent variables (i.e. x_1 and x_2). A linear regression equation is of the form $y = a_o + a_1x_1 + a_2x_2$.

As for the previous case, the "Multiple Regression Coefficient" can be found and the level of significance determined.

5.4.6 The Practical Value of Regression

It should be noted that the regression equation does not give an exact figure for either fixed or marginal consumption. If the correlation is significant it provides a very good estimate of

Figure 5.4.3 Regression Analysis for Steam Consumption Against Weekly Output for a Factory

(Reference: O Lyle - Efficient Use of Steam (6))

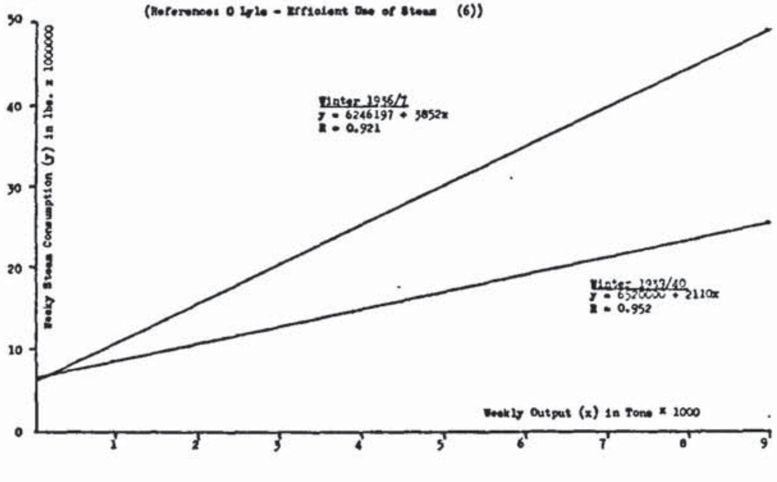


Figure 5.4.4 Fiducial Limit Bands

(Reference: O Lyle - Efficient Use of Steam (6))

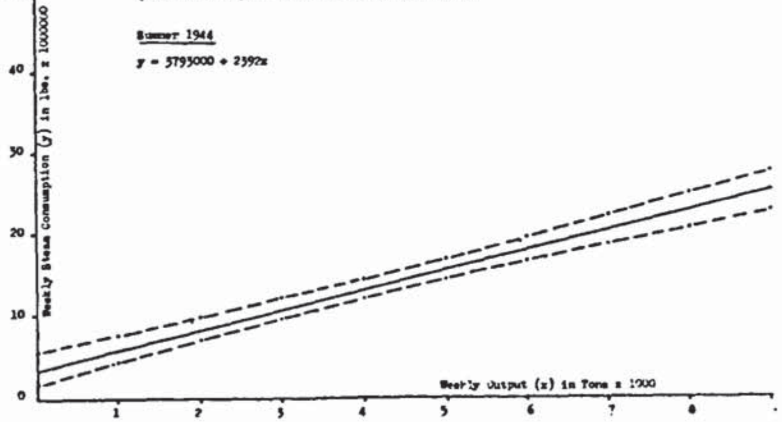


Figure 5.5.1 Relationship Between Degree Days and Fuel Consumption

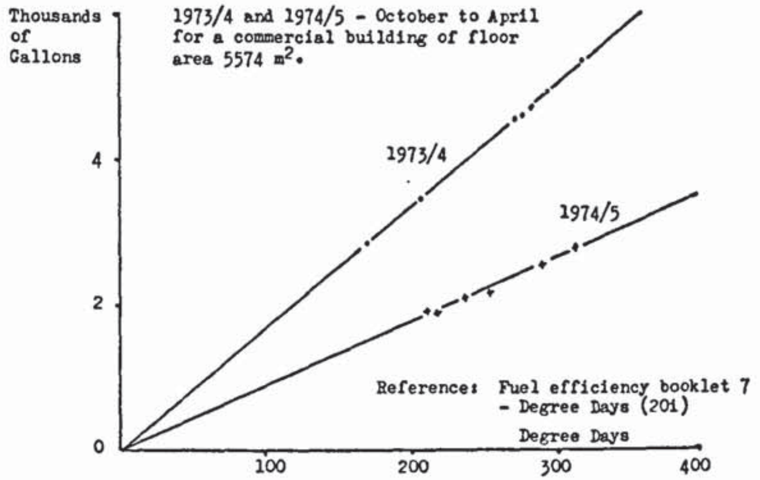


Table 5.5.2 Data for the Above Graph

Period	Degree Days (C) 1973/4	Degree Days (C) 1974/5	Fuel Consumption (Gallons) 1973/4	Fuel Consumption (Gallons) 1974/5	Gallons / Degree Day 1973/4	Gallons / Degree Day 1974/5
O	172	237	2842	2049	16.5	8.6
N	286	237	4686	2084	16.4	8.8
D	319	218	5318	1886	16.7	8.7
J	280	254	4586	2152	16.4	8.5
F	274	291	4544	2510	16.6	8.6
M	296	313	4904	2763	16.6	8.8
A	207	212	3469	1910	16.8	9.0
Total	1834	1762	30349	15357	16.6	8.7

marginal but not fixed values. Based on studies of the literature (6) (141) (10e) (140a) and initial exercises (345) in regression analyses the following points of caution must be raised:

a. There is a need to assure the data is accurate and meaningful.

b. There is a need to identify as many variables as possible and to find their respective effect on consumption, otherwise regression statistics do not have a great deal of significance.

c. It is probable that only like processes can be compared for effectiveness of usage of energy.

d. It is only possible to form a judgement if the statistical significance is first proved.

e. Assuming the major influences have been identified, the results are likely to be more meaningful if the boundary definition is small; i.e. a department or factory as opposed to the industrial categories as chosen by P. C. Roberts (10e)(140a).

5.5 Degree Days (20i)

The generally accepted definition of a degree day is the daily difference in °C between a base temperature of 15.5°C and the 24 hour mean outside temperature when it falls below this. It has always been clear that more heat is required to maintain a home, office block or factory at a comfortable temperature in cold weather than is required in warmer weather. Experience has shown that in the U.K., 18.3°C is considered comfortable for normal domestic purposes.

Tests and experiences both in the U.S.A. and the U.K. have confirmed the following:

a. The heat requirements of building, which maintain an interior temperature of 18.3°C, are more closely related to the amount by which the exterior temperature falls below 15.5°C. This is explained by the difference (2.8°C) being a simple adjustment for all the additional heat sources such as people, lifts, cooking appliances, lights etc., contributing to the total requirements. Naturally this figure may vary with occupancy, standard of insulation, building design etc., but for normal use 2.8°C is acceptable.

b. Secondly, heat consumption in any given period depends upon temperature and time. A 1°C difference (15.5 - 14.5°C) maintained for one day of 24 hours is called 'one degree day'. If the outside temperature remained at 14.5°C for each day of a week, 7 degree days would accumulate.

If a second week's temperature was constant at 13.5°C, 14 degree days would accumulate. From this it can be inferred that the fuel consumption for the second week would be roughly twice that for the first. The basis for these deductions was regression analysis.

Degree day data may also be used to establish whether fuel used for heating is consumed efficiently. In the first instance, a direct comparison may be made between the fuel consumed over a period with corresponding degree days, the plot of which is line 'A' in Figure 5.5.1. Month to month variations in fuels used may be explained by proportional changes in degree days or the 'fuel used per degree day' as given in Table 5.5.2. Here a conservation action can be assessed on a common basis, independent of weather variation.

5.6 Basis for the Dunlop Investigation

5.6.1 Assumptions

a. All controlling variables were defined as mutually independent.

b. The data used was accurate and valid for the periods stated, as much as possible being derived from actual measurements.

c. The volume of data was sufficient to permit possible high levels of significance. Correlation was only presumed at high levels of significance.

d. The efficiency of energy use over the chosen period remained unaltered.

e. Variations in the critical properties of the energy sources (i.e. pressure and temperature of steam) remained small during the period.

f. Variations in controlling factors relative to energy use remained small during the period.

g. The data used was collected over a defined time scale.

h. The investigation was limited to the Fort Dunlop site.

i. High degrees of scatter, for the most part, force the adoption of the linear equation.

Based on the preliminary investigations of section 5.8, only first and second order equations were considered viable.

5.6.2 Factors Influencing Energy Usage

The list of variables given below were deemed most likely to be instrumental in dictating how energy is consumed at Fort Dunlop.

Direct Quantifiable Variables

a. Production Output

b. Ambient Temperature/Degree Days

c. Direct Manhours/Total Manhours/Number of Employees

d. Numbers of heating or machining cycles

e. Numbers of process stages

f. Number of chemical changes

g. Numbers of components in the product

h. Age of plant

i. Percentage of raw material converted to product

j. Percentage recycling

k. Processing times (Curing Cycles)

l. Process temperatures and pressures

m. Floor area

n. Roof area

o. Building Volume

p. Daylight hours to total hours of operation ratio

Indirect Quantifiable Variables

q. Cost of Energy

r. Product cost and energy intensiveness

s. Fixed capital investment

t. Profit margin

u. Maintenance to production cost ratio

Unquantifiable Variables

v. Product type

w. Product range

x. Attitudes of people

y. Geographical location

z. Company policy

In addition to the above, one energy form was compared with another (i.e. steam vs fuel consumed by the boiler plant).

For the purpose of this exercise, only the first three independent variables were considered. This was due to the limitation of time and the availability of accurate data.

5.6.3 Forms of Energy Considered

There are a number of forms of energy used within the Fort Dunlop site. These are listed in Table 5.6.1 along with a number of uses and the more obvious controlling variables. Of these, however, it was only possible to obtain accurate data relating to total fuel, electricity, town water, borewell water, steam and compressed air. It is these which have been used in the analysis. All units used were physical (i.e. MJ, m^3 etc.) and not monetary (37).

5.6.4 Data Used

As in all real situations, particularly in a factory having diffuse energy usage, the quality of the data collected is imperfect. Without representative and valid data, any analysis becomes a wasted effort. The data used in this case was obtained from the Fort Dunlop Works Accounts records for each month during the years 1969 to 1976 inclusive. Naturally these are subjected to error. However, any anomalies which have appeared (i.e. the three

day working week of January 1974) were examined before the analysis took place.
Whilst it is realised that data collected relies as much on guesswork and estimates due to the relative deficiency of effective measurement facilities, the majority must be assumed to be valid. The validity of the data will reflect strongly the dependability of the results obtained. A period was spent with the Works Accounts and Instrument Departments, to obtain a full appreciation.

One of the outstanding problems has been to reconcile the level of production output each month with the actual activity level in the factory. The existence of interfactory sales (IFS) of products within the group has introduced difficulties. Whilst IFS is accounted for in monetary terms, no allowance has been made for inclusion in energy analysis. For example, if the site's steam consumption is x and the reported production output is y, the specific consumption of steam to produce the product is x/y. However, the real production output is y + IFS = z. Hence the real specific consumption is smaller than the original estimate by an amount = x/(z-y). This has the effect of reducing the reported specific consumption from anything up to 10%.

Due to the unavailability for each month in the period, production output data does not include IFS. The effect of this on the analysis will be to raise the specific energy consumptions. Secondly the actual gradient of the regression line (assuming a linear relationship) will be greater than actual, since specific consumption tends to get smaller with larger output. It is unlikely that the plant energy overheads will alter and, therefore, the intercept will remain unchanged.

Table 5.6.1

Possible Forms of Energy for Consideration

Energy Source	Type of Use		Possible Influencing Factor
a. Electricity	mechanical power	-	production output
	lighting	-	floor area
	domestic hot water	-	no. of employees
	chemical (electrolysis)	-	time
b. Fuels (coal, gas, oil)	space heating	-	building volume
	process heating	-	production output
	hot water	-	water used
	transport	-	mileage
c. Steam	space heating	-	building volume
	process heating	-	production output
	steam raising	-	fuel used
d. Hydraulics	process	-	manhours worked
e. Compressed Air	process	-	manhours worked
f. Vacuum	process	-	steam used
g. Cold Water	domestic	-	no. of employees
	process	-	production output
h. Hot Water	domestic	-	no. of employees
	process	-	curing cycle time
i. Solar Gain		-	area of South facing roof
		-	lights and windows.

Figure 5.6.2

Steam or Fuel vs. Production Output

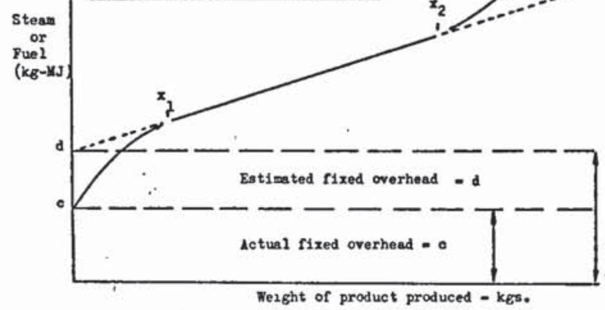


Figure 5.6.3

Steam or Fuel vs. Production Output

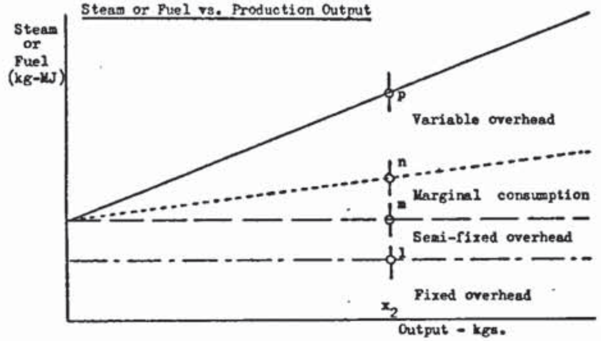
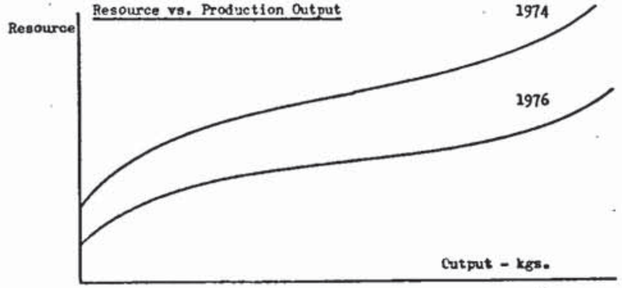


Figure 5.6.4

Resource vs. Production Output



Finally, the data collected relates to the entire site. No account has been taken of production and non-production segregation.

5.6.5 Case 1 : Independent Variable = Production Output

At this point it is appropriate to hypothesise the results which could be expected from polynomial regression. For the most part only first and second order polynomials are considered since it is unlikely, with data validity already in question, that much credibility can be given to higher orders, albeit that these might well give higher correlation.

The most obvious and common relationship between production output and one of the above mentioned dependent variables is the first order polynomial equation as shown in Figure 5.4.3 (6). Examination of the graph shows that consumption is made up of a 'fixed' unvarying component and a 'marginal' directly varying component. The fixed component is often referred to as the 'energy overhead' and is comprised of items such as distribution loss, leaks, operational loss, space heating etc. The fixed component is, therefore, a function of the building and process design, the effectiveness of thermal insulation, the efficiency of energy conversion processes and the operation procedures. These are but a few of the possible influences, most of which cannot be measured directly.

The marginal consumption indicates, amongst other things, the degree of energy intensiveness. The greater this is, the more energy will be required for each tonne of product and hence the steeper the gradient of the line.

Whatever the dependent variable, there will always be some fixed overhead caused by energy consumption other than that directly attributable to production output. (See figure 5.6.2). In the case of fuel and steam, such overhead 'c' may constitute the effect of space heating of buildings, if the period taken relates to constant ambient temperature. For periods encompassing temperature variation, the effect would be to introduce a higher degree of scatter of 'noise' amongst the points, since both temperature and production output are independent. Alternatively, a large value of 'c' might well result from high distribution loss, leakage etc.

In many instances the value of 'c' can alter for similar outputs. This leads to apparent inefficiency of resource utilisation on the basis of specific consumption. A factory in the tropics, for example, could well have a lower specific steam usage than say Fort Dunlop, due to the absence of space heating. Interfactory comparisons can only be obtained if some account is made for the remaining independent variables. Multiple regression helps to improve the analysis.

The overhead, being a function of partially dependent criteria, can be reduced to a minimum through good housekeeping, maintenance and operating practice, and through alterations to the plant and process.

As production volume increases from zero, so should the effective use of resources improve. This is primarily due to the reducing overhead/marginal ratio. Most plants, however, are designed to run at a particular output range (x_1 to x_2) where the dependent factor is expected to vary linearly. The gradient of the line is a measure of the effective conversion of energy into some useful product, through good control and operational practice.

Above or below the design range, the effective use will decline as shown in the graph. Here the relationship is non-linear. In the upper echelons, the effects on energy consumption of overtime and weekend working tend to bear this out. At the lower end, the necessity to keep plant running continuously at low output also upholds the theory. Due to the effect of overhead and the upper efficiency limit, therefore, the optimum operating level would be at production output x_2. In practice, however, it is difficult to establish this point due to scatter and uncertainty of the order of the polynomial. Many factories can and do operate in the region beyond x_2 due to production commitment from sales demand etc. Here resource utilisation tends to be poor, indicating the need for suitable planning.

It is unlikely for production and economic reasons that output would be allowed to fall below a certain level,at which point production would cease (i.e. x_1). Assumption can, therefore, be asserted that the linearity continues to a new intercept d. This introduced a higher value than expected for the overhead. The difference (d - c) might be explained as the physical resource attributable to plant overhead but eliminated immediately production ceases. An example is the effect of continuing heat loss from presses when idle during slack production periods. Fort Dunlop operations do not always incorporate such control.

The possibility of second and third order fits cannot be ignored. With the curve shown in figure 5.6.2, a cubic equation might seem very probable. In practice, however, with large scatter, the linear solution is more appropriate. Non-linearity tends to be caused by poor control of resources and usage.

If linearity is accepted, it is possible to draw up further inferences as shown in figure 5.6.3; best understood by means of an example. If steam consumption is related to output, four components can be attributed to the relationship:

a. The fixed overhead such as distribution losses, space heating etc. (at $x_2 = 1$)
b. The fixed overhead which exists only when the plant is 'switched' on (at $x_2 = (m-e)$)
c. The marginal consumption component directly relating to the product, thus forming chemical bonds within the product (at $x_2 = (n-m)$). At Fort Dunlop this is small.
d. The marginal consumption component relating to output but independent of the useful energy retained in the product during manufacture; i.e. heat loss during the cure cycle (at $x_2 = (p-n)$). This might be termed the 'variable' overhead.

The important consequence of this is the division of conservation effort into four categories:

a. Reducing the fixed overhead by reducing distribution loss through better lagging, reduction of leaks etc.
b. Improving the thermal insulation of specific plant to reduce losses when it is in operation.

c. Changing the process of curing rubber by adopting a new process such as injection moulding or micro-wave curing.

d. Increasing the efficiency of energy performance by altering the operating, good housekeeping, increased cycle frequency for curing, etc.

These clearly relate to the conservation categories previously identified. Of course what is gained on one hand could easily be lost somewhere else. For example, reduced heat loss through better press insulation will provide less space heating in that area and consequently a demand for additional primary heat. Hence a variable steam overhead suddenly becomes a fixed overhead, which could well be more difficult to control (i.e. by employees opening doors). It may even produce additional consumption since the presses are isolated at weekends whereas the space heating might be left on.

Models derived in this way identify the possible consequences of contemplated actions as well as pointing to the type and effectiveness of utilisation. Similarly, assessment can be made of the theoretical energy needed to produce a product, identifying the scope for improvement. Finally, by considering the pattern of use over a period, comparisons with the performances of previous years can be made (See Figure 5.6.4). Here the example shows not only a decrease in marginal steam consumption but also in fixed overhead.

Scatter is a problem with all correlations. Assuming there is only one controlling factor, i.e. production output, the more effective control will render a lower degree of scatter. This should become evident when comparing correlations for electricity, a relatively controllable resource, with those for steam or fuel. Confirmation of this is apparent when anomalies, such as a 'three day working' week, are considered. For steam the specific consumption will tend to be higher than expected, whereas that for electricity will be near normal. Tighter control over resources and plant will not only render higher performance efficiency, but also a closer dependence on production activity. For example, there is evidence that most of the electricity used at Fort Dunlop goes directly into producting the tyre or rubber compound. Over 55% is accounted for in Fabric and Compound preparation, where the use is strictly for mastication, 19% for other production related purposes and only 26% for overhead such as lighting etc. Hence the more consistent variation of specific consumption with output.

Steam on the other hand, may attribute half its demand in the winter to space heating, thus contributing greatly to the fixed overhead, completely independent of production activity. Hence at low activity levels, the specific consumption is high due to the controlability being poor in relation to consumption.

5.6.6 <u>Case 2 : Independent Variable = Resource</u>

It is often useful to compare the consumption of one resource against another: steam vs fuel, energy vs water, compressed air vs electricity; the correlation reflecting the conversion efficiency of a piece of plant.

Depending on the method of accounting used, the total number of manhours in a factory can be divided into direct and indirect categories, worked by each employee directly involved in production output (i.e. in physically making tyres).

Indirect manhours are defined as the sum of the number of hours worked by each employee who is not directly involved with production output but is associated with the process (i.e. engineering maintenance). The sum of both direct and indirect which gives the total manhours worked. It is interesting to note that the difference between direct and total manhours is mostly the activity overhead. It may be possible to attribute resource consumption to each of these, with a higher degree of correlation.

Staff employees also use energy, water and other resources. With accountability for this group being more difficult, absolute criteria cannot be used. The effect of staff will, therefore, be to either vary the degree of scatter or contribute to the fixed overhead. Using manpower as a basis for comparison, however, the following should be possible:

a. There will be a simple relationship between direct manhours and production output.

b. In the case of steam/fuel, a close relationship with total manhours is likely. This would reinforce the hypothesis that energy consumption, and hence conservation, is 'people' dependent at Fort Dunlop.

c. This assertion may not be true for electricity, since a greater portion of electrical energy is consumed in the less labour intensive process.

Electricity might well correlate to the installed/operating capacity of rubber mills, and hence the capital investment in this plant.

d. For energy consumption plotted against total manhours, the marginal consumption would tend to reflect the 'direct' elements and the fixed overhead the 'indirect'.

e. This would not be the only component of fixed overhead. Lighting, heating etc., would all contribute.

f. As in previously stated cases, it may be more advantageous to consider manhours in relation to energy consumption; corrected for specific deviations such as temperature variation.

Employees directly concerned with production could influence efficiency of energy use through consciensious operation but do not have any control over actual flows, leaks and design. Engineers, indirect labour involved with maintenance and control, would realise this capability but are also subject to weekend working and thereby adversely increase energy overheads.

If the hypothesis of 'people dependence' is true, it would also be true to say energy conservation will only be effective if people have awareness, the right attitude, the motivation, commitment and responsibility instilled into them; thus obviating the need to involve the social sciences in the programme.

5.6.7 <u>Case 3 : Independent Variable = Ambient Temperature</u>

As for production output vs fuel consumed, where results will be subjected to the effects of temperature variation, ambient temperature vs fuel will be affected by production variation. This will be seen as 'noise' in the correlation resulting from influence on both fixed overhead and marginal components. Once again temperature vs specific consumption might be considered; but since the latter also varies with product output, the real answer can only be provided by multiple regression of all three variables.

The heat transfer equations for conduction, convection, and radiation are (132):-

$$Q_k = k.A. \frac{dT}{dx} \quad \text{i.e.} \quad Q \propto \frac{\text{Temperature difference}}{\text{thickness}}$$

$$Q_c = L.A. \; dT \quad \text{i.e.} \quad Q \propto \text{Temperature difference}$$

$$Q_r = K.A. \; T^4 \quad \text{i.e.} \quad Q \propto \text{Temperature to power 4}$$

Where Q = rate of heat transfer for the three modes

k = thermal conductivity

h = overate heat transfer coefficient

K = radiation constant proportional to emissivity, transmissivity and the Stefan Boltzman costant.

A = area

T = temperature

x = thickness

For most purposes, ultimate heat loss is due to the atmosphere. Relatively little is conducted into the ground. Similarly at temperatures below 260°C (500°F, the temperature of super-heated steam at Fort Dunlop), approximate transfers of heat are:

Q_c = 28.4 MJ/m^2hr (25000 Btu/sq.ft.hr.)

Q_r = 0.1 MJ/m^2hr (10 Btu/sq.ft.hr.)

Hence the predominant forms of heat transfer in Fort Dunlop are convective and conductive. If the latter is small in terms of ultimate loss, the fuel/steam consumption is proportional to the temperature difference and to surface area of plant, machines and buildings. Hence the relationship is linear.

Taking surface area as a constant, the larger the temperature difference the greater the heat flow or loss. Assuming the steam supplied is for space heating, which is only turned on when the outside temperature falls below 15.5°C (20i), consumption increases linearly with declining temperature. The gradient is a function of the coefficient of heat transfer, influenced by weather effects, surface configuration, degree of ventilation etc., and surface area. (See figure 5.6.5).

Temperature is an uncontrollable variable. Building design and the number of air changes, however, can be optimised to give lower gradients. Similarly, the degree of insulation will reduce surface temperature and lower consumption. Simple saving actions should, therefore, be identifiable in a model.

If the only data available is site steam usage, the relationship will no longer hold,due to the that used in production. In this case either multiple regression or specific consumption vs temperature would be needed. Assuming specific steam usage to be constant at all production levels, the relationship would tend towards that shown in Figure 5.6.6, the fixed overhead being attributable to production. Using such analysis, the quantity of steam lost to space heating and the atmosphere can be differentiated from that useful to the process. For Fort Dunlop, the latter is likely to be small, since the energy retained in chemical bands is infinitessimal compared with that dissipated to the atmosphere (16).

In theory, there should also, be a point of inflection at 15.5°C, after which the specific heat loss should decline at a less rapid gradient as the ambient temperature increases to a value equal to the average surface temperature of the plant and buildings. The degree of insulation will affect this.

Due to poor controllability of heating, however, there will be no clear cut turn-off point at 15.5°C. Most environments are in-fact at a room temperature 20°C, resulting in the heat being unnecessarily supplied at far higher ambient temperatures. Similarly heating will often be applied for longer periods than necessary, thus introducing a time element. This will tend to increase the gradient. With the probability of inefficient control, inconsistent design and varying conditions, it is more likely that a curved relationship will result (See Figure 5.6.7). As the ambient temperature falls, the consumption will tend to increase more rapidly until a point is reached where the boiler output has reached its maximum.

It is important to attempt some assessment of the magnitude of steam used for heating purposes alone. At the time of writing, this facility was not wholly available in Fort Dunlop. Once the space heating element is accountable, improvements through insulation and control can commence. In addition to the normal temperature correlation, degree days might also provide a suitable independent

Figure 5.6.5 Theoretical Plot of Heat vs. Temperature

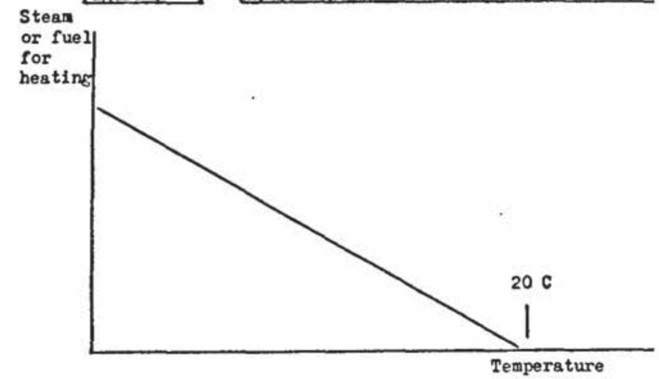


Figure 5.6.6 Temperature vs. Total Heat input to Factory/Output Ratio

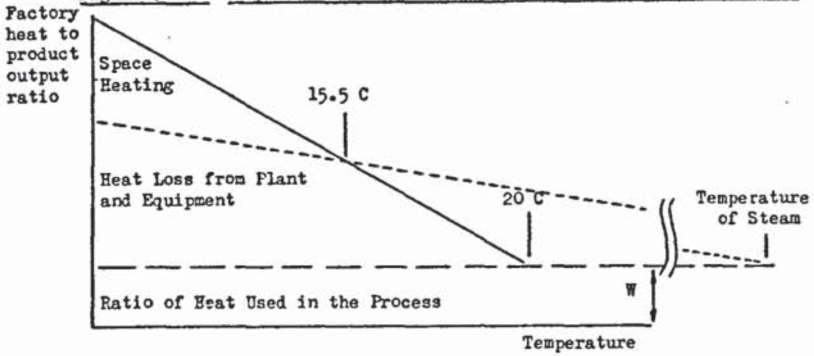


Figure 5.6.7 Probable Curve for Temperature vs. Specific Consumption

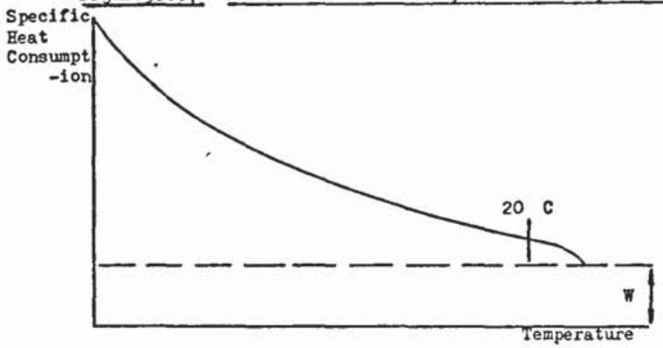


Figure 5.6.8 Cost of Energy vs. Energy Efficiency

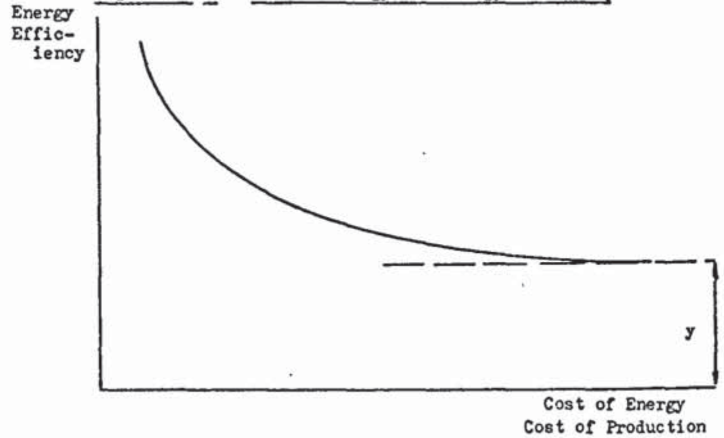
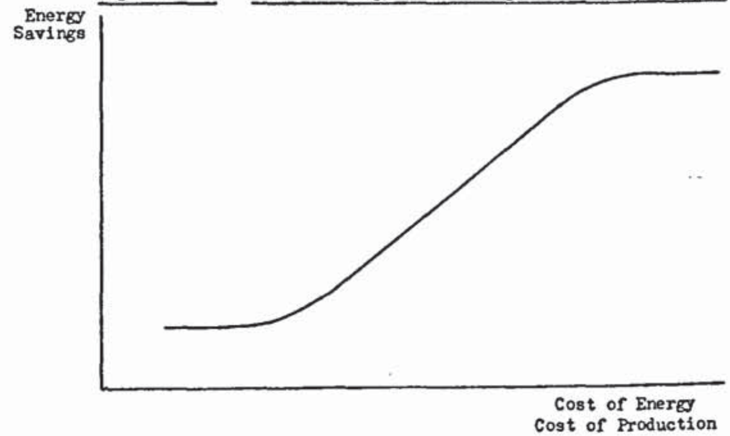


Figure 5.6.9 Cost of Energy vs. the Degree of Energy Savings



variable for both analysis and future accounting functions. This will also be considered in a multiple regression exercise.

5.6.8 Case 4 : Independent Variables = Alternative Factors

The list of possible independent variables is large. A possible useful correlation would be steam consumption vs curing cycle times. Alternatively electrical consumption in compound preparation will most likely depend on the number of mixing stages. Similarly total consumption must be strongly related to the percentage scrap produced and the degree of recycling in the process.

The converse arguments also hold. As is suspected with product output variation, there is indication of null-hypotheses. For example, the number of daylight hours to hours or darkness is unlikely to relate to lighting loads since lights are continually left on when not required during the day as well as at night. Lighting is more likely to correlate to some unquantifiable variable such as peoples attitude and awareness of energy. Whilst intriguing in theory, attitude being arbitrarily measurable in some forms, it is a subject for the social scientist.

Extending this thinking a little further, correlation of energy efficiency with the cost of energy would produce a useful measure of the acceptance of conservation philosophy within a factory. There are many factors which might motivate a company to save energy, market force being the most predominant.

The type, size and age of plant, the energy intensiveness, the available capital for investment and the fixed capital assets must also be included. A possible correlation is efficiency vs energy intensiveness. In theory, the higher the intensiveness the greater the effort to conserve the resource. Assuming specific consumption to be a suitable measure of performance, the gradient of the curve will gradually decline to some asymptote (y), (Figure 5.6.8) beyond which is increasingly difficult to improve efficiency due to the effects of the asymptotic technological limitation.

Such proof would give an indication of the importance of costs in providing incentives for energy conservation. For the domestic consumer, the pattern is more likely to hold due to the direct effect of market forces on the individual. Industry, however, not only suffers from poor employee attitude towards energy but also has the facility of passing the price rise onto the consumer.

Effective introduction of conservation can also be studied in other ways. Savings achieved plotted against intensiveness might give the conventional 'S' shape efficiency curve with technological constraints forcing the upper limit (See Figure 5.6.9). Where percentage energy costs are low, there is likely to be less incentive than when they are higher. This could introduce evidence that energy conservation activity is greater in some industries than others, simply on the grounds of intensiveness. Alternative independent variables such as profit margin, turnover etc., might also be considered. Comparison could also be made between process and 'batch' type industrial operations. The relationship between conservation and the various types of industry will dictate the future energy policy.

5.7 Data

The data was made available by Fort Dunlop Works Accounts and constituted monthly statistics for the years 1969 to 1976 inclusive. This was the only continuous data available for this factory. It does not differentiate between the resources used for production and those used elsewhere.

Data was also collected for consumptions relating to other factories both within the U.K. Tyre Division and other Company Groups. It was not possible to amass this information over a sufficient time scale,nor in adequate quantity to gain a reasonable level of significance. Computation and analysis were,therefore, restricted to manual assessment.

Meteorological data was made available by the Watnall Office, Nottingham (National Grid Reference SK 503456), and Birmingham (Elmdon) Airport. Recorded temperatures relate to monthly averages. Degree Days (201) are based on 15.5° datum level. All statistical data is given in Appendix A.

Prior to the main computer run, trial exercises were carried out to establish the feasibility of carrying out a full scale analysis. These took the form of hand-calculations and graph plotting based on a smaller collection of data. The significance was judged pictorially on the apparent degree of scatter. The data was then fed into the H.P. Plotter Pack to obtain a more accurate fit and a measure of correlation.

Table 5.8.1

List of Results Obtained from the Polynomial Regression Exercise

			Appendix Figure
A.	Production Output (W) vs.	- Total Fuel (F)	A6
		- Electricity (E)	A7
		- Total Energy (Z)	A8
		- Town Water (A)	A9
		- Borewell Water (B)	A10
		- Steam (S)	A11
		- Comp. Air & Hydraulics (C)	A23(a)
B.	Ambient Temperature (T) vs.	- Total Fuel (F)	A12
		- Total Energy (Z)	A13
		- Steam (S)	A14
		- Specific Fuel (J)	A15
		- Specific Steam (K)	A16
C.	Production Output (W) vs.	- Direct Manhours (G)	A17
		- Total Manhours (H)	A18
D.	Total Manhours (H) vs.	- Total Energy (Z)	A19
		- Steam (S)	A20
E.	Steam (S) vs.	- Total Fuel (F)	A21
		- Town Water (A)	A22
F.	Manual Investigations UKTG	-	
G.	Water (A) vs.	- Fort Dunlop Fuel (F)	A24
		- UKTD Fuel (F) & Energy (Z)	A25
		- Dunlop UK Fuel (F), Energy (Z)	A26

5.8 Results of Polynomial Regression

Appendix A, section A.2, outlines in detail the results obtained from the polynomial regression exercises. A list of the results is given in Table 5.8.1.

5.8.1 Concluding Comments

The equations most representative of the best fit to the data are summarised in Table 5.8.6. For the most part, with a few exceptions, correlation between variables was low, indicating a need for further analysis. Poor control of resources, effects of secondary independent variables (i.e. temperature), changes or improvements in efficiency and data accuracy account for the degree of scatter. Those resources such as electricity and manpower, which are less dependent of these, exhibit higher significance. For the remainder, multiple regression analysis is needed to achieve greater reliability.

The three day working week, affecting two months at the beginning of 1974 appeared to have a remarkable effect on steam and fuel consumption, but not on electricity or compressed air. The reason for this anomaly is obvious. Firstly, at low output, the steam/fuel overhead to total consumption is proportionally higher at lower output levels. If the plant operated for only three days in the week, this overhead would be even greater than normal due to additional start-up and shut-down requirements. Secondly, it was necessary to keep the plant warm in these cold months. Thus increasing the specific consumption. Thirdly, unlike electricity, control of steam/fuel consumption is difficult.

Table 5.8.6

SUMMARY OF CORRELATION RESULTS FOR POLYNOMIAL REGRESSION

	Symbols	Units per month	Regression Coefficients Const.	1st order	2nd order	Scatter-Average Fluctuation %	Corr. Coeff.	Significance	Remarks
Production Output	W	10^6kg							Limits 1·6 mkg to 9.2 mkg
Total Fuel	F	TJ	26.37	25.52	1.30	8.4		Low	Requires multiple regression with temperature
Electricity	E	TJ	5.19	5.06		3.9		V.high	Acceptable relationship
Total Energy	Z	TJ	27.42	32.23	1.14	7.1		Marginal	Requires multiple regression with temperature
Town Water	A	10^3m^3	18.61	27.88		8.6		Low	Marginally acceptable
Borewell Water	B	10^3m^3	15.62	13.19		13.4		V.low	Apparent independence of production output
Steam	S	10^6kg	9.47	8.79		11.5		V.low	Requires multiple regression with temperature
Temperature	T	C							Limits 0·1°C to 19·2°C
Total Fuel	F	TJ	323.45	-17.12	0.35	10.3		V.low	Requires multiple regression with output
Total Energy	Z	TJ	362.41	-17.97	0.36	9.6		Low	Requires multiple regression with output
Steam	S	10^6kg	86.41	-3.69	0.04	10.2		V.low	Requires multiple regression with output
Specific Fuel	J	MJ/kg	47.48	-1.37	0.02		0.52	Low	Insufficient number of points
Specific Steam	K	kg/kg	15.73	-0.68	0.02		0.70	Marginal	Insufficient number of points
Production Output	W	10^6kg							Limits 1·6 m kg to 9·2 m kg
Direct Manhours	G	10^3hrs	47.10	53.75		3.4		V.high	Acceptable relationship
Total Manhours	H	10^3hrs	78.10	52.64		5.2		High	Acceptable relationship
Total Manhours	H	10^3hrs							Limits 161·4 hrs. to 586·8 hrs.
Total Energy	Z	TJ	13.75	0.59		6.1		Marginal	Acceptable relationship
Steam	S	10^6kg	4.62	0.15		11.3		V.low	Requires multiple regression with temperature
Steam	S	10^6kg							Limits 21·9 m kg to 95·8 m kg
Total Fuel	F	TJ	18.52	2.71	0.009	6.4		Marginal	Acceptable relationship
Town Water	A	10^3m^3	70.15	1.72		12.6		V.low	Unacceptable
Production Output	W								Limits 1·6 m kg to 9·2 m kg
Comp Air & Hydraulics	C	TJ	0.9	0.95				Marginal	Acceptable relationship based on manual analysis

The results basedon water correlation suitable conclude that energy consumptions do vary with the amount of water used. Although equations cannot always be formulated,the trend does exist. As a quantitative means of effective measurement of energy performance, the questions still remain. Measuring water consumption might be easy cheap and accurate but this can only be a guide to the expected energy use,since high energy intensive operations do not necessitate comparative 'water' intensiveness.

In all cases, specific consumption varies with increases in the indendent variable. With production output as the controlling factor this can be extensive. Based on the results,therefore, the present Fort Dunlop method for performance measurement must be inaccurate. The use of manhours as a base may be more significant.

Having established the set of regression equations it should be possible to check their accuracy or find other correlations through normal algebraic procedure. For example, based on 5,000 tonnes output, the sum of the fuel and electrical energy required can be obtained from $Z = F + E$ (= 216.96 MJ per month)

where $F = 26.37 + 25.52\ W + 1.30\ W^2$

$E = 5.19 + 5.06\ W$

Alternatively calculation can be made directly using:

$$Z = 27.42 + 32.23\ W + 1.14\ W^2 \quad (= 217.07 \text{ MJ/Month})$$

The major differences are produced from effects at the extremes of the operational usage. These cannot be ignored.

Electricity use is for the most part independent of temperature, which must contribute to the variances in overhead when F vs T is compared with Z vs T (= 38.96 MJ/Month). Taking an average

Table 5.8.7

Specific Consumption vs Output

W 10^6kg	S/W kg/kg	F/W MJ/kg
1	18.26	53.19
2	13.53	41.31
3	11.95	38.21
4	11.16	37.31
5	10.68	37.29
10	9.74	41.16

Table 5.8.9

Specific Consumption (Activity Base)

H 10^3hrs	S/H kg/hr
100	196.2
200	173.1
300	165.4
400	161.6
500	159.2

Figure 5.8.8

Specific Consumption vs Output

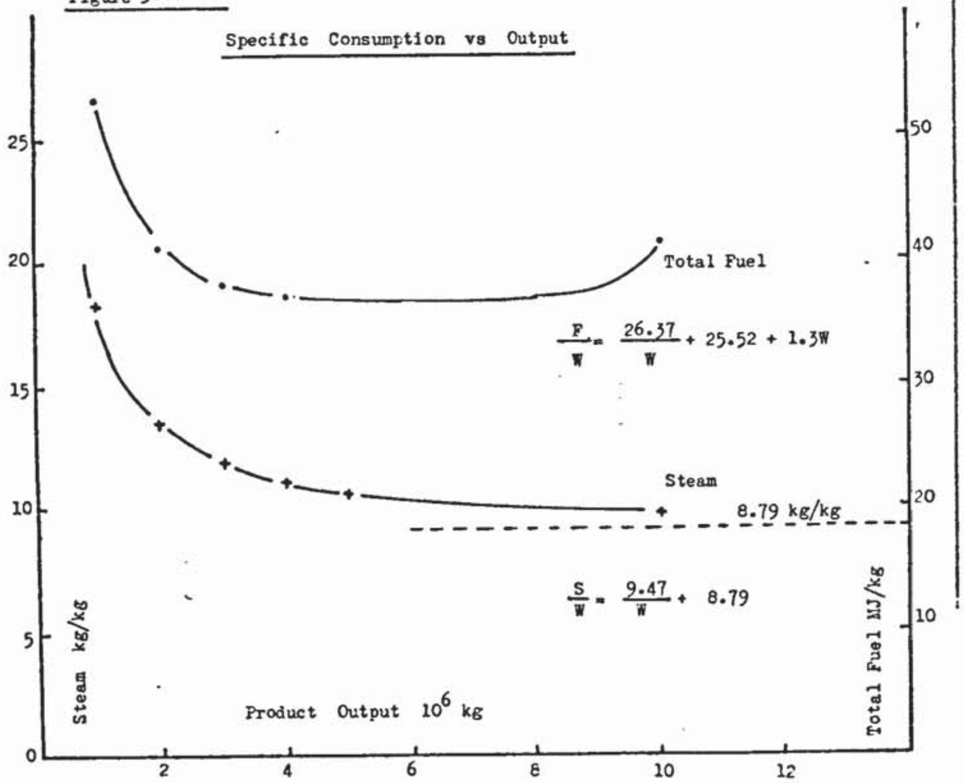
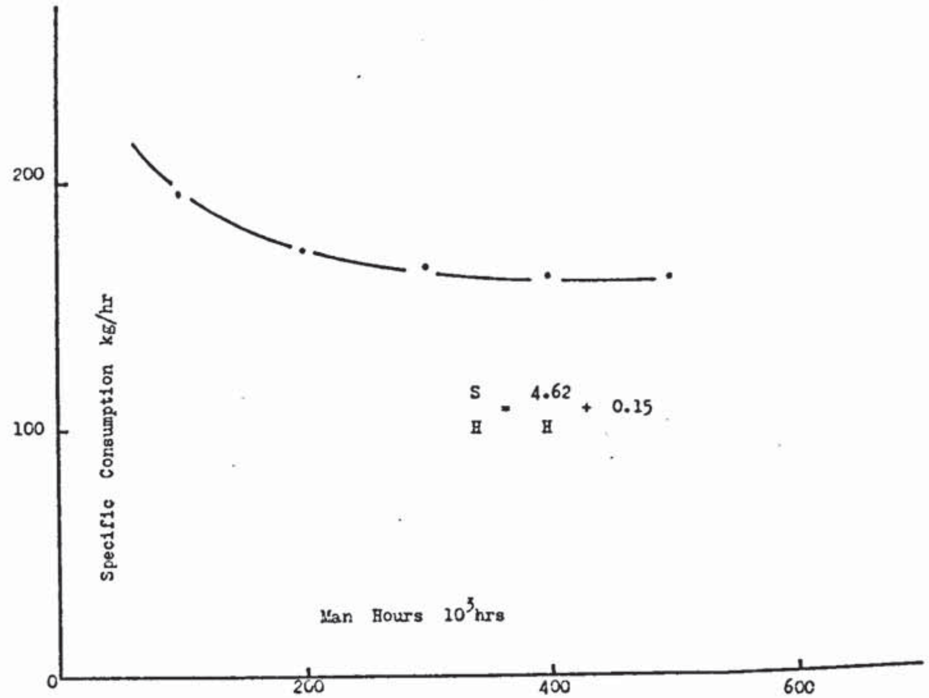


Figure 5.8.10

Specific Consumption (Activity Base)



electrical consumption at 5,000 tonnes output it= 30.49 MJ/Month .

Having derived tentative relationships between consumptions of energy sources and production activity, it was deemed unnecessary to repeat the polynomial analyses for the respective specific consumptions. With production output as the independent variable, adaption of the equations to relate specific consumption rendered results in accordance with theory (Table 5.8.7 and Figure 5.8.8).

Both equations give a sharp improvement in specific use as production output increases. For steam, the rate of reduction declines as W increases to give an asymptote to 8.79 kg/kg, which is the lowest possible level with the present Fort Dunlop plant. Having a second order function, specific fuel consumption reaches a minimum of 37.23 MJ after which increase occurs with higher W.

In contrast specific consumption based on manhours remains almost constant throughout (Table 5.8.9 and Figure 5.8.10). This is due to the small overhead and rapid reduction in specific usage to the asymptote (150 kg/manhour for steam). Consequently, manhours could provide a better base for performance measurement.

Whilst most of the resultant correlations appear to reflect both the theory and the practical operation, significance still remains low. From bivariate analysis, however, the assumption that specific consumption is a valid means to performance appraisal has been disproved.

5.9 Multiple Regression - Comprehensive Results

Inadequacies in the results of investigations involving simple polynomial regression on bivariate relationships enforced this need to analyse energy consumptions relative to a number of independent variable in the same equation.

Deductions from the earlier polynomial regression exercise showed a need for multivariate correlations involving heating steam, fuel or energy, since these sources were used for both process and space-heating requirements. The following outlines the results obtained from multiple regression of:

Energy vs Production Output and Ambient Temperature.

Energy vs Production Output and Degree Days.

Steam vs Production Output and Ambient Temperature.

Steam vs Production Output and Degree Days.

The SPSS - Multiple Regression Package (154) was employed to this end, the data and detailed results being given in Appendix A, section A.3.

5.9.1 Conclusions

A summary of the regression equations obtained from Multiple Regression Analysis using the SPSS package (154) is given below.

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

$$Z^{*} = 39.67 + 24.89\,W + 0.27\,D$$

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

$$S = 4.9 + 6.18\,W + 0.09\,D$$

where Z is the total energy consumption TJ/month.

S is the steam consumption in 10^6 kg/month.

W is the production output in 10^6 kg/month.

T is the average ambient temperature in ^{o}C.

D is the total number of degree days per month.

* Note. this is a revised equation and not the original regression result.

With each equation, it appears inaccurate to attempt to isolate the effects of component contributions. Each must therefore be used in its entirety. For example, ambient temperature effects will influence both process and space heating consumptions. Consequently, it is impossible to establish the space-heating content of the equation without additional information. In addition, part of the heating load appears as a constant due to heat being lost at temperature $> 15.5^{o}$C (the theoretical threshold for commencement of heating).

Resultant significance, and hence credibility, is high. On statistical grounds, each equation is acceptable. However, certain questions might be posed as to the accuracy of overhead assessment. Results apart, further query might point to the reliability of the data and the collection period. Finally, there is no assurance that the basic assumption of linearity for each independent variable would not be better than other polynomial functions, although results from the bivariate regression tended towards this.

The basic benefit must be the improved analysis for measurement of energy performance in the factory. The effects of production output fluctuation and climatic changes are accounted, leaving a normalised energy consumption. Based on monthly values of W, T and D, values of total energy and steam consumptions can be found. When compared with the actual consumptions, a coefficient of performance can be derived. For example

$$Sc = 4.9 + 6.18\,W + 0.09D$$

$$Sa = Sc.\ X$$

where Sc = calculated steam used

Sa = actual steam used

X = coefficient of performance

If $X < 1.0$, an improvement has been achieved. If > 1.0 inefficiency is present. It should be noted, that conditions are the same for both Sa and Sc.

As intimated by M Moulder (37), budget / variance analysis cannot be a basis for performance measurement. Present systems do not allow for variations in heat loss due to climatic change or for effects of altering production output. This system rectifies the defficiency.

An alternative arrangement to the above method is to normalise the effects of overhead and climate and compare the specific consumption to the derived constant. For example:

$$\frac{Sa - (4.9 + 0.09D)}{W} = 6.18$$

This too is a useful equation since 6.18 becomes the optimum specific steam consumption for Fort Dunlop, using the existing process, plant, equipment and buildings. Consumptions below this level must indicate an improvement and vice versa.

It is useful to relate all energy and steam loss to a single variable. The value provides a simple unit whereby all consumption, with the exception of the 4% which is retained in the product, can be related to a temperature. At specific production levels this value is defined as the equivalent ambient temperature which would have to be reached for all loss to become zero. It is of course nothing more than a hypothetical value, since losses are not entirely dependent on radiation convection or conduction (i.e. air leaks). However, the values when related to actual monthly temperatures will tend to provide a qualititative measure of performance.

The results of this multiple regression exercise, together with the high degree of significance must pose severe threat to the creditibility of employing the comparable results obtained from the polynomial analysis. It must be concluded, however, that identification of specific losses or improvements may still be outside the dection sphere of the procedure. For example, this analysis has been based on global factory data. The obvious progression is to attempt similar analysis on ever decreasing defined areas to the departmental level; a subject for future work.

5.10 Energy Performance Models for Fort Dunlop

The following section summarises the models put forward in this chapter. The objective was to analyse the performance of energy consumption relative to all influencial conditions. The model equations are given in Table 5.10.1.

In each case, the value of an energy service is calculated from the equation given and compared with the actual value obtained for that month. If Nc is the value calculated and Na is the actual value, then the coefficient of performance is given by:

$$X = \frac{Na}{Nc}$$

For improvements in the effective use of energy, X must always be less than unity.

Budgetary control is the traditional method of alerting management to areas needing investigation. This technique suggests a second source of information supplementary to, and not a replacement for, budgetary control.

The cost of implementing the new model system is thought to be small. Depending on the data available, it could cost no more than 10 man days to set the system up, and just an hour a week or month to record the actual against the estimate and to write a short report outlining possible areas requiring further investigation.

TABLE 5.10.1 Summary of Regression Equations to be used in Assessing Energy Performance

			Units/Mth.
Total Fuel	F	$= 35.54 + 36.36W - 2.77T$	TJ
Total Fuel *	F	$= 31.60W + 0.27D$	TJ
Electricity	E	$= 5.19 + 5.06W$	TJ
Total Energy	Z	$= 40.73 + 41.42W - 2.77T$	TJ
Total Energy *	Z	$= 5.19 + 36.66W + 0.27D$	TJ
Town Water **	A	$= 18.61 + 27.88W$	$10^3\ m^3$
Borewell Water **	B	$= 15.62 + 13.19W$	
Steam	S	$= 26.78 + 7.55W - 1.09T$	10^6 kg
	S	$= 4.90 + 6.18W + 0.09D$	10^6 kg
Compressed Air & Hydaulics	C	$= 0.9 + 0.95W$	TJ
Total Energy	Z	$= 13.75 + 0.59H$	TJ
Steam **	S	$= 4.62 + 0.15H$	10^6 kg
Total Fuel	F	$= 18.52 + 2.71S$	TJ
Total Water **	A	$= 70.15 + 1.72S$	$10^3\ m^3$

* Signifies estimated equation

** Signifies poor correlation

Where

			Limits	
Production output	=	W	1.6 - 2.2	10^6 kg
Ambient Temperature	=	T	0.1 - 19.2	C
Degree Days	=	D	423 - 31	
Total Manhours	=	H	161.4 - 586.8	10^3 hrs

This system is simple to operate and flexible in the control method. Extended down the line to individual departments or areas, complete control can be realised.

It is difficult to visualise how a yearly budgetary ritual, based on guesswork, can adequately monitor the constantly changing conditions in a factory. This model, however, is able to do this adequately.

5.11 Appraisal of Regression Theory in the Identification Process

The objective of this work was to evaluate the potential of regression theory as a means towards improved performance measurement and hence identification of energy loss. In part, the results of the exercise were encouraging.

The proposed model relies heavily on the validity of the data used. This data relates to past events and, in practice, may no longer represent the true situation. Accuracy and reliability of measurement, adequate records and interpretation present initial difficulties. Similarly, throughout the period taken, changes in product specification and plant efficiency will have altered energy requirements. Finally, it is doubtful whether the measured production output is a true representation of activity, since this is only a value of finished top-grade tyres exported and does not include interfactory sales or second grade products.

The measurements of energy consumption reflect usage over the entire site. With a large percentage being attributable to non-productive activities, future analysis might include data which would make this distinction, reflecting energy used only for the production of tyres.

The time space used to amass sufficient data for this analysis is believed to be adversely lengthy. Many of the difficulties mentioned would be eliminated if the data had been collected weekly over the past 24 months, which would be more representative of present day conditions.

In any energy analysis, it is imperative that calculations be based on physical energy units and not on cost. An increased cost per unit weight of product may indicate the effects of a price rise and not a drop in efficiency. The costing element should only be added once the true performance level has been assessed.

No matter how sophisticated the analysis, regression analysis can at best only provide an educated feel for exact results even at high correlation and significance levels. Correlations are, therefore, mostly limited to first and second order equations.

Many variables are not independent and in the case of simple regression, correlation will rarely rest with just one controlling factor. Some of the resultant scatter may be reduced with manipulation of data which would of course detract from the validity of the exercise. For example, obvious anomalies may be omitted from the data. Whilst multiple regression provides a more suitable answer to the problems, there are still variables, such as employee attitude, which defy accurate quantification.

There are however, a number of distinct advantages in adopting this procedure in diffuse climates where, in the absence of nothing better, the results could have some significance.

Specific consumption (MJ/kg) forms the present basis for performance measurement. One of the first consequences of this work identifies the inadequancies of the assumption that specific values remain unaltered throughout the range of working conditions. Non-linearity, effects of fixed overhead and influence of changes in ambient temperature invalidate this hypothesis. The new model, however, normalises effects of changes in temperature and output thus giving a truer measure of plant and process performance.

It can be argued that production variation should not be normalised, since a negative budget variance of output reflects inefficiency. Likewise, the effects of percentage scrap or recycled material should be detectable, since these too govern efficiency. Although ambient temperature is uncontrollable, the degree of building, plant and pipe insulation is under the influence of the engineers. Should the effects of temperature be left in as well?

To the engineer, and for that matter the production manager, the important criteria is plant and process efficiency. It is imperative that month to month comparisons be made relating to common production conditions. The objective is to identify the problems brought about by ineffective energy use through losses, poor operation, bad maintenance or high scrap/recycle of materials. Once this is achieved, it is then easy to revert to simple specific consumption comparisons to see the effect of low output or high degree days.

Budgetary control, with problems associated with specific measurement already identified, is on its own an inadequate indication of performance. The new model provides a much improved method of comparing actual consumptions with expected consumptions under the specified conditions of output and temperature; he coefficient of performance being the measure of effective energy usage. It is difficult to gauge whether specific improvements or losses would be identifiable at this level, but in principle the technique is a valid means to identifying inefficiency.

Based on the equations for Total Fuel and energy in Table 5.10.1, comparison of two months give the following results:

	Jan 1969	Jan 1976
Z a (10^6MJ)	344.2	165.2
F a (10^6MJ)	304.5	144.6
W (10^6kg)	6.1	3.4
T (^{o}C)	5.3	6.1
Z c (10^6MJ)	278.7	164.7
F c (10^6MJ)	242.7	142.3
X fuel	1.25	1.02
X energy	1.23	1.00

Hence percentage improvements in use of fuel and energy are 18.4% and 18.7% respectively. When basing comparisons on specific consumption, improvements are 14.8% and 13.9% respectively. Specific consumption fails to account for the lower production and higher temperatures in January 1976, resulting in an apparently smaller improvement. Since the increased efficiency was produced from the installation of a new boiler house, it can be concluded, therefore, that large changes car be identified.

Whilst discussing budgetary control, a basic requirement of general management is to judge output and consequent expenditives with reference to the annual management plan. This presents no problem to the new model for energy performance, since values of production output planned and average temperatures based on past records may be used in the equation to determine the 'budgeted' service consumption. Against this, the actual may be reviewed. Alternatively, if only the effect of lower product output is to be assessed, the 'budgeted' service consumption may be calculated using the specific temperature for the month in question. This demonstrates the flexibility of the model to determine different effects.

The high significances of the multiple regression results enforce their adoption preference over the polynomial results. It must be stressed, however, that individual components taken out of the context of the equation may be unreliable. Some bivariate results, such as the electricity - production correlation, are highly significant and can be used directly. Others, such as borewell - production analysis, render low correlation and must be treated with care. In general water has a high overhead and fails to relate to either energy (apart from general site figures) or production. It cannot, therefore, be used as a clear indicator of energy use.

Low fixed overhead makes activity levels (manhours) a suitable guide for energy consumption and indicates that services usage could be 'people' dependent. Multiple regression apart, energy usage per manhour is a better guide to performance than the production output counterpart. If 'non-factory' consumptions and temperature correction were accounted, even higher correlation could be expected.

It is interesting to note that for all the cases examined, the highly controllable energy forms (i.e. electricity) give the highest correlation. Water usage is not easily controlled and consequently has low correlation.

One aim of the exercise was to determine what type and how much energy was being lost. For example,was it possible to identify marginal, variable overhead, and fixed overhead consumption? The answer is - doubtful. The high degree of scatter found with some regressions limits credibility to segregation. This is particularly true with fixed overhead where the confidence intervals are large. Such items as space heating, non-production and other components cannot successfully be assessed. Rough estimates may be found from combining several equations in a suitable fashion to reveal the desired result.

In conclusion, it must be stressed that whilst the proposed method partially fulfils the objectives, small changes cannot be identified. For this, more detailed analysis at a lower level (i.e. individual departments) must be made. The model as it stands, however, does warrent some credibility even if this is no more than the platform for further investigation. It is proposed that the equations given in table 5.10.1 be implemented at Fort Dunlop and tested alongside the present budgetary system.

There is still much work to be completed before reliable models can be drawn up. Future work might include non-factory/production/departmental segregation; inclusion of the remaining influencing-factor combinations given earlier in the chapter and as yet untried; further analysis of activity regression; and finally analyses of the remaining factories within the Tyre Division.

The ultimate aim is to produce standardised models, based on the same methodology, for assessment of energy performance throughout the U.K. Tyre Division. Ideally it would be beneficial to compare factories, but production and temperature effects are not the only criteria to be normalised. Energy consumption also varies with building condition, type of process, type of product etc.

CHAPTER VI

THERMOGRAPHY, A REMOTE SENSING TECHNIQUE

6.1 Chapter Preview

Diffuse energy users suffer the indignity of being unable to analyse energy flow patterns, consumption levels or efficiencies. Traditional techniques for determining energy consumption and efficiency appear time consuming, costly and often impossible under normal operating conditions. In 1975, therefore, alternative means were sought of assessing energy flows and losses. Whilst simple analysis, statistical techniques based on specific measurements, and studies of remote sensing of snow melt on rooftops were no less important contributors to the solution, it was believed that 'Thermography' - the study of remote sensing of temperature using total infrared radiation measurement techniques - offered the greatest potential. The site chosen for the investigation was Fort Dunlop.

This chapter introduces the topic of Thermography, firstly examining the theory of infrared (IR) radiation, and later demonstrating how this can be measured to give quantitative values of surface temperature. A summary of the type of equipment, operating procedures, applications and computation requirements are given. The chapter is concluded with the summary of the Thermographic Research Objectives.

6.2 Basic Principles Of Radiation

It is not necessary to expound at length the theoretical principles of radiation. For the purposes of Thermography it suffices to give no more than the brief description given in Appendix I. Summarising, radiation in the wavelength 0.1 to 100 μm when incident upon a body will heat it and is consequently called thermal radiation. It is this radiation which is of interest to the concept of Thermography.

6.3 Introduction to Thermography

The discovery of the infrared portion of the electromagnetic spectrum was made accidentally in 1800 by Herschel (156) during a search for new optical material. Herschal set up a systematic investigation, repeating Newton's prism experiments, but looking for the heating effect. Passing a blackened thermometer along the colours of the spectrum, he found that temperature readings showed a steady increase from the violet to the red, forming a maximum point outside the visible spectrum. He referred to this new portion as the 'thermometrical spectrum'. The work 'infrared' only began to appear in print around 75 years later, the originator remaining a mystery.

In 1830, Mellani (156) discovered that naturally occuring rock salt, made into lenses and prisms, was remarkably transparent to the infrared. By the 1930's synthetic crystal growing had been mastered providing materials which were transparent far into the infrared spectrum.

Thermometers, as radiation detectors, remained unchanged until 1829, the year Nobili (156) invented the 'thermocouple'. Later Melloni developed the 'thermopile', bringing sensitivity to 40 times that of the best thermometers. This could detect heat from a person standing 3 meters away. The first so-called 'heat picture' became possible in 1840, the result of work by Herschel's son - Sir John. Based upon the differential evaporation of a thin film of oil when exposed to a heat pattern focused upon it, the thermal image could be seen by reflected light through the interference effects of the oil film. The primitive record of the thermal image on paper he called a 'thermograph'.

Inventions by Langley in 1880 (bolometer)(156), Dewar in 1892, and others led to the continuing comprehensions of infrared. At the start of the century many patents were issued for devices capable of remote detection of personnel, artillary, aircraft etc. Progress was infused by the need for military exploitation. The most sensitive systems up to this time, however, were based on Langley's bolometer idea, where radiation focussed upon a thin blackened strip of platinum produces response on a sensitive galvanometer. The period between the wars, however, saw the development of two revolutionary detectors: the image converter and the photon detector.

At first the image converter received the greatest attention by the military because it enabled an observer to 'see in the dark'. However, sensitivity was limited to the near infrared wavelengths; the most interesting military targets had thus to be illuminated by infrared search beams, with the risk of discovery of the observer.

These inadequacies led to post 1939-45 war development of 'passive' (no search beam) systems based on extremely sensitive photon detectors. The secrecy of such techniques, did not begin to be lifted until the mid 1950's. From that time, adequate thermal-imaging devices began to avail themselves to civilian science and industry.

6.3.1 Infrared Camera Development

As recently as 1960, image - scanning times of 10 minutes or more were required to produce a useful thermogram; limiting the usefulness of infrared systems to observations of fixed objects of stable temperature patterns. This was finally overcome during the 1960's in Sweden, when AGA (156) developed 'Thermovision', the first commercial real-time thermographic system, based upon a high speed image scanner using rotating IR - prisms.

Most earthbound objects are too cool to emit detectable radiation in the wavelengths of visible light unless above the 'red hot' temperature. The wavelengths at which the radiation emitted by everyday objects, such as people, plants, building etc., centre around 10 μm deep in the so-called 'far infrared'. Thermography makes use of and measures radiation in this infrared spectral band, which is the entire band extending from visible light to microwave radio wavelengths. The infrared band is commonly further subdivided into four lesser bands. These include = 'near infrared' (0.75-3 μm), the 'middle infrared' (3-6 μm), the 'far infrared' (6-15 μm), and the 'extreme infrared' (15-1000 μm).

Some confusion has existed in the past concerning the term 'infrared photography' as contrasted with thermography. The distinction is one of wavelength. Conventional 'infrared film' photographic emulsions are sensitive to wavelengths no longer than 1.2 μm. Astronomers call the wavelength - span 0.75 to 1.2 μm the 'photographic infrared spectrum'. Beyond the 2 μm wavelength lies the so-called 'thermal infrared'. Infrared photography exploits the differences in the absorptive and emissive properties of surfaces. It depends upon the reflection of very short infrared wavelengths generated by outside sources such as the sun, which are much hotter than the object. In contrast, thermography detects radiation 'emitted' throughout the entire infrared (IR) spectrum.

Early infrared camera designers were faced with a difficult problem. The use of sensitized film as the image conversion medium was prohibited to them. Even if an adequate film had been available, practical constraints would have prevented its use due to the film being sensitive to the ambient heat of the camera box itself. An IR camera using heat - sensitive film would need to contain a 'heat - tight' box. This could only be achieved if the entire camera box were cooled to very low temperatures, an extremely difficult design requirement. Instead, designers reduced the size of the infrared - sensitive material to a small spot, chilled by a Dewar flask containing liquid nitrogen and shielded from heat emitted by the camera housing. Finally, optical mechanical scanning was employed to produce a visible, raster-line picture of the infrared image.

The technique of producing pictures from the visible thermal radiation constantly being emitted, absorbed and re-emitted by objects is called 'thermography'. Details of infrared theory and thermography, the equipment, and the operation procedures are given in Appendix I.

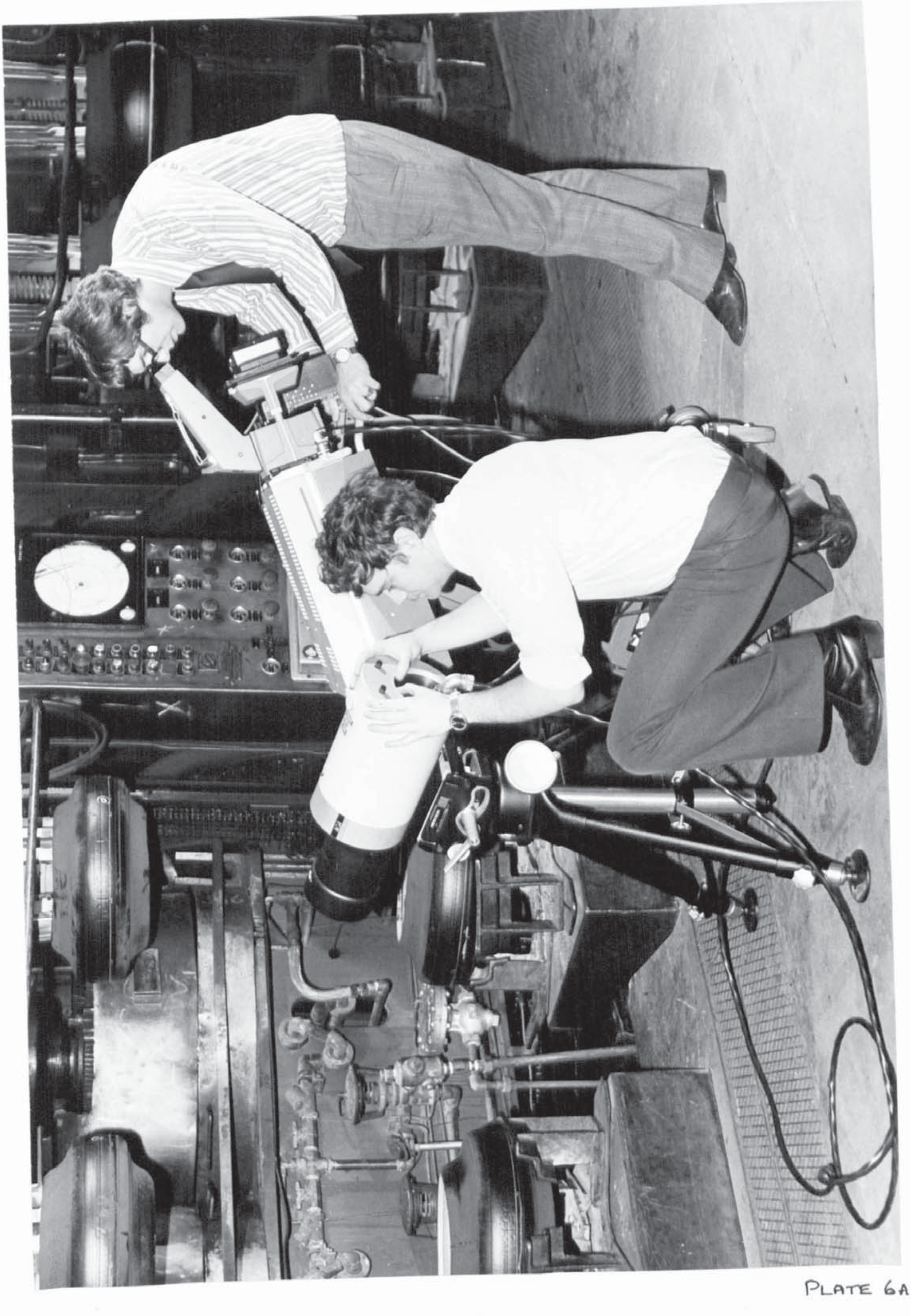


PLATE 6A

at wavelengths beyond 40 μm.

6.3.2 General Applications

Thermography has been developed as a tool to measure the temperature of various types of surfaces. Although a relatively new concept, its potential as a non-destructive testing method is already apparent. Notable applications are given in Tables 6.3.1 (a) and (b).

In addition to the qualitative survey potential, quantitative data can also be gathered by calibrating the temperature of the 'hot spots' uncovered in the survey. This information can be useful in developing priorities and in estimating the magnitude of the heat loss, and might even extend to the assessment of heat balances.

6.3.3 Thermography for Identifying Industrial Energy Loss

The analysing of energy flow patterns, consumption levels and efficiencies in many traditional industries has already been shown to be difficult. Whilst process manufacturing patterns may give greater control of energy usage, multi-product batch-type patterns do not. Here energy use is diffuse. Simple analysis and statistical techniques could not provide all the answers. The obvious option was to view the site as a complete entity, through some simple technique, preferably visual, to identify the major problem areas. Each of these could then be examined in turn resulting in a final "homing-in" on the origin of the loss.

As with other useful but limited techniques, simple direct visual identification did not provide many answers. There was a need for a more rigorous test. Contemplation established a second phase progression namely the study of melting snow. This technique

Table 6.3.1(a)

Practical Uses of Thermography

Medical - Body or tissue malfunction produces local increases in temperature. Depth of burns, brest cancer, success of skin grafts, circulation problems etc. can readily be identified. (161)

Thermal Pollution - Aerial mapping of land masses, water ways and urban districts identify hot surfaces, heat losses and thermal flows in water and atmospheric discharge.

Buildings - As well as identifying the heat loss from building structures, the somewhat less obvious detection of 'infiltration' problems through draughts, poor lagging etc. can be shown. (157) (158) (159) (160).

Thermal Uniformity - Heat emitters (radiators) can be analysed for variation in surface temperature.

Product Temperature - Assessment of the point at which a product (i.e. milled rubber) has reached its critical process temperature can be made.

Boiler, Furnace or Heat Exchanger Malfunction - Flaws in casings, insulation or operation are readily identified.

Hot Spots - Identifying unwanted heat loss from plant and equipment or buildings becomes a simple procedure. The same technique, using a microscope attachment, can be used to analyse problems with small circuit board components. (156)

Refrigerant Flow - The influence of low as well as high temperatures can be evaluated by analysing the 'cold' spots.

Leaking Valves - Passing valves controling thermal fluids can be identified.

Electrical Components - High amperage connections, transformers, and other components exhibit increased temperature in areas of whole or partial malfunction.

Moisture Measurement - Measurements of variation in infrared absorption are increasingly being used for moisture control in production operations. (161).

On Line Product Analysis - Defects or non-isotropic properties highlight flaws, inconsistency or thickness variation in standard manufactured products. These exhibit detectable temperature variation. A common example in the tyre industry is inconsistency in extrusion or calendering of rubber.

Casting Wall Thickness - Inclusion of voids in a casting appear as pattern variations in a thermorgram.

Coating Thickness - Thickness influences heat emissivity, thus thermography can be used to ensure coating integrity. (162).

Bands and Welds - Density differences, voids, inclusions in metals, ceramic materials and laminated sections can be checked by heating the product to uniformity and noting the variation relative to same standard. (162).

Tyre Analysis - Hot spots in tyres can be pinpointed. The unwanted heat build-up usually indicates impending tyre failure.

Temperature Differentials - Variation in heat flow through composite materials and insulation can be noted through detection of temperature profiles.

Exhaust Patterns - Thermograms can show both the magnitude and location of various temperature gas (or liquid) discharges. (162).

Stress Analysis - Propogation of stress through an element or thermally induced stress can be analysed from time-lapse or sequential thermograms.

TABLE 6.3.1b

Other Applications of Infrared Thermography (158)

Inspection of power transmission equipment

Water leakage into building roof insulation

Detection of geological formations

Inspection of cooling or heating coils for blocked tubes

Spotting air locks in tubes

Studying the behaviour of thermal sealing equipment

Investigating ultrasonic sealers and sealing operations

Hot injection moulding problems

Studying the behaviour of heating and cooling devices

Finding leaks in buried thermal fluid pipes

Inspection of machinery bearings

extended identification to include the otherwise 'invisible' heat loss from buildings by remote sensing.

Stage 1 constituted investigations of snow-melt on Fort Dunlop roof-tops. The results of this exercise are laid down in Chapter VII. From the onset, however, it was clear that the procedure had its limitations, the most obvious being the relative infrequency of snow falls of suitable consistency in the UK during the year. Neither did melting snow give any indication of losses in the buildings or any reliable quantitative measurement. A progression was, therefore towards the use of thermography.

Since all common surfaces radiate energy, thermography has the capability of showing temperature differences and profiles in the form of a 'real-time' thermal picture. Detection of energy loss was therefore possible. Thermography potentially fulfilled all the basic criteria for effective measurement through the capability of remote sensing of whole site areas to individual components, the facility for actual measurement of surface temperature,simple pictorial representation,and significant accuracy.

6.4 Thermographic Equipment and Operating Principles

(See Appendix I)

6.5 Measurement of Temperature

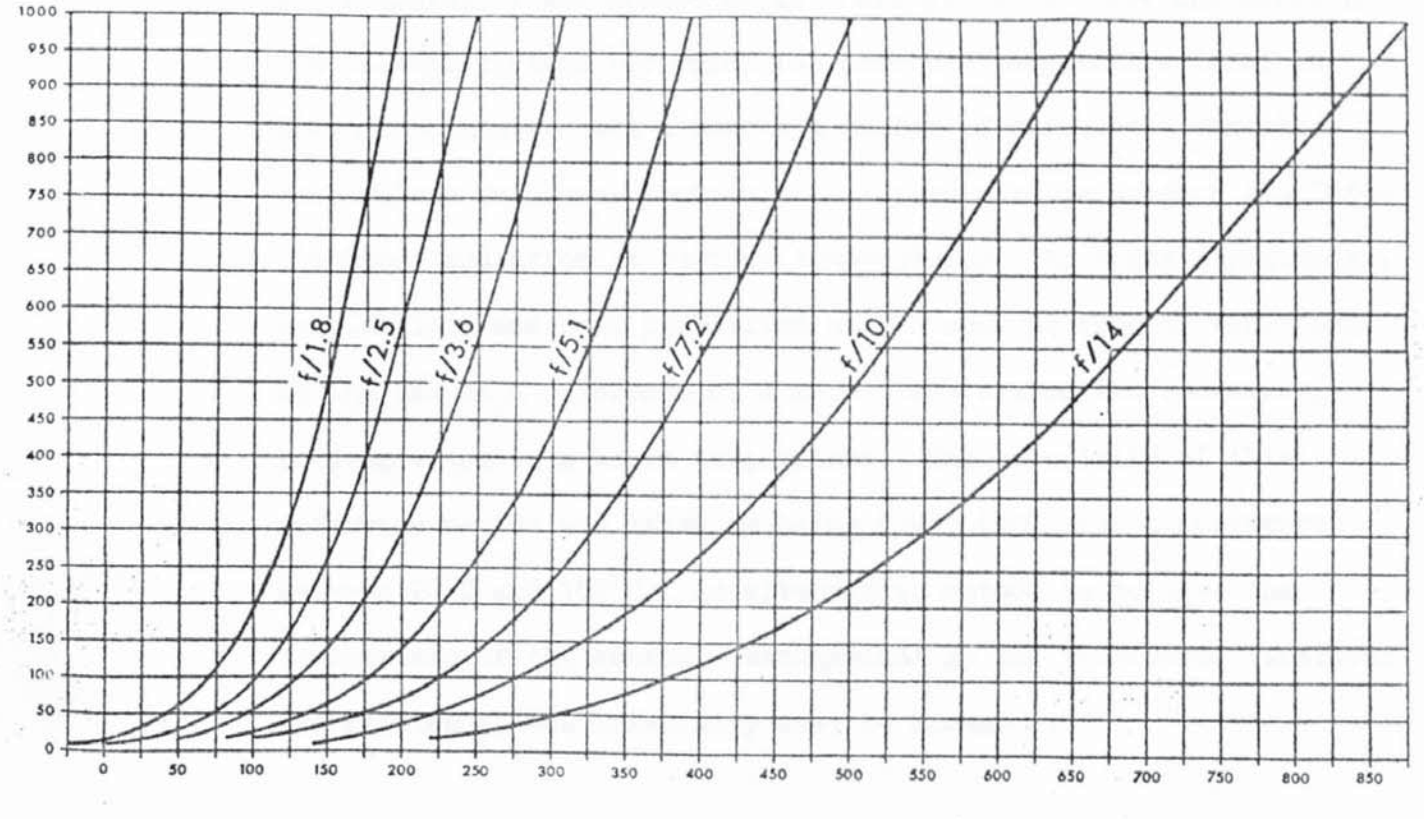
With the exception of a narrow range corresponding to the human body, the AGA 680 cannot present direct temperature readings. Reference needs to be made to calibration curves. This is due to the highly non-linear relationship between the radiation intensity and the temperature which produces it. (See Figures 6.5.1). Between 20° and 40°C, which includes the temperature of skin surfaces on the human body, the curves are for the most part linear, allowing direct-readout to be made. There is a separate calibration chart for each f/stop selected.

6.5.1 'Isothermal Unit' Readout

The camera isotherm controls allow observation of temperature contours on an object within the span selected by the sensitivity control (Figure I.4.9). The effect on the picture is to portray isotherms as saturated white, the temperature span of which is adjusted by the isotherm width control.

Figure 6.5.1(a)

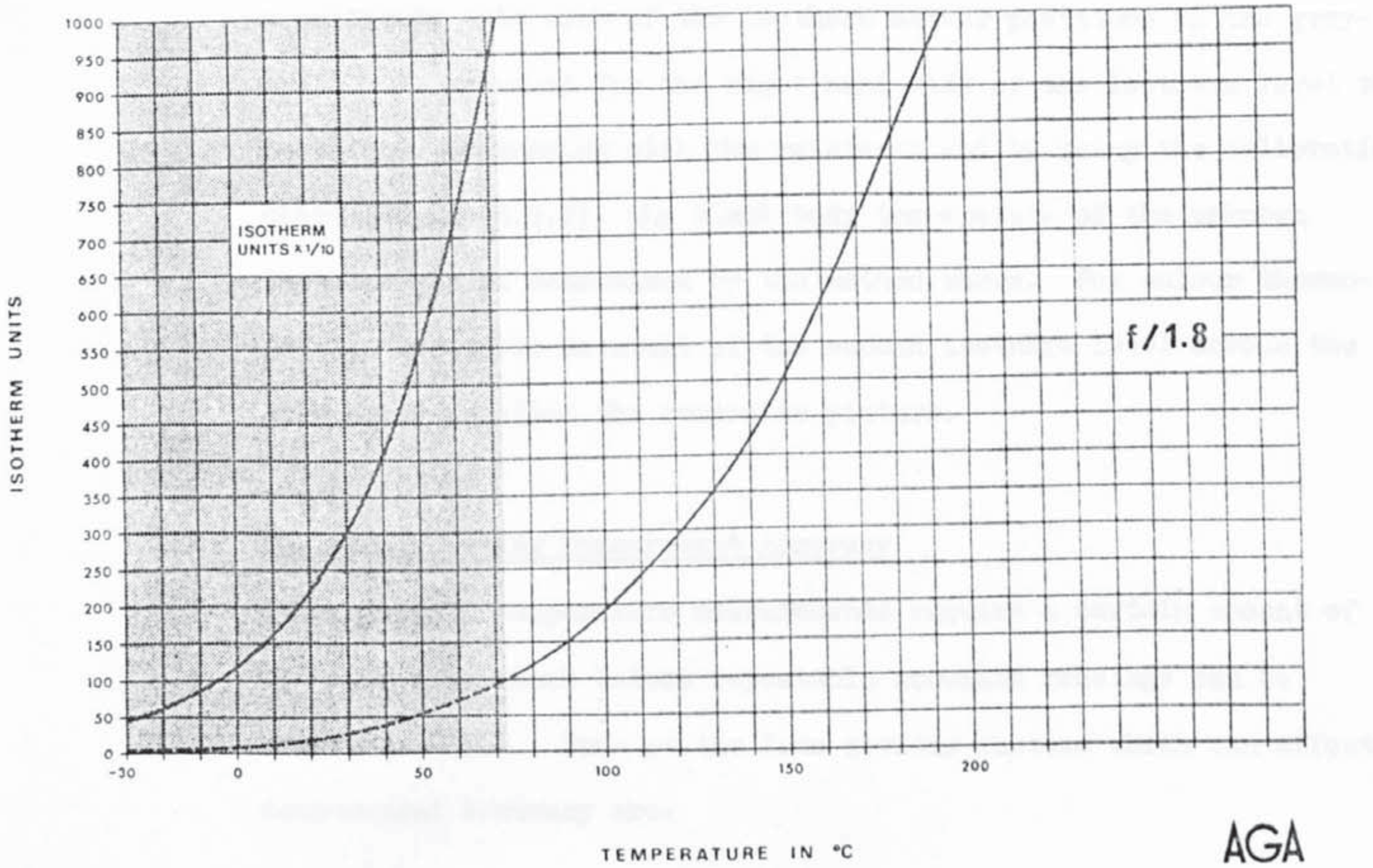
AGA THERMOVISION® SYSTEM 680
Typical* calibration curves -30° to +850°C



* Averaged from typical production system-response curves.

Figure 6.5.1(b)

AGA THERMOVISION® SYSTEM 680
Typical* calibration chart -30° to +190°C



* Averaged from typical production system-response curves

It is useful, if not essential, in thermography to have one point in the thermal picture for which the absolute temperature level is known accurately. AGA produces a number of calibrated variable-temperature reference sources, regulated to produce simulated blackbody radiation at various temperatures. In these experiments, availability and cost prohibited use of such equipment, resulting in the use as a reference of a matt-black coated tin container, holding water at a known temperature. The emissivity of this reference source was taken as being 0.91, (157) for temperatures between 20°C and 150°C. An alternative method is to take the temperature of the general 'background' as the reference. Whatever the reference, the emissivity must be known.

Having selected the most appropriate f/stop setting, adjusted pictorially one isotherm to correspond to the reference and selected the second isotherm to correspond to the area whose temperature is to be found, the 'isotherm units' can be derived from a multiple of sensitivity with each of the isotherm marker positions on the grey-scale. It is usual for the right hand side of the isotherm level to be taken. Commencing with the reference and by using the calibration chart (Figure 6.5.2), the black body temperature of the unknown isotherm can be determined by the method shown. For colour thermograms, successive movement of the second isotherm level across the grey scale provides the composite picture.

6.5.2 Factors Affecting Measurement Accuracy

Thermographic temperature measurements require a certain amount of operator experience before repeatable accurate readings can be expected. (156). Some of the less obvious factors which can affect measurement accuracy are:

Figure 6.5.2 Using the Camera - Aperture Calibration Curves

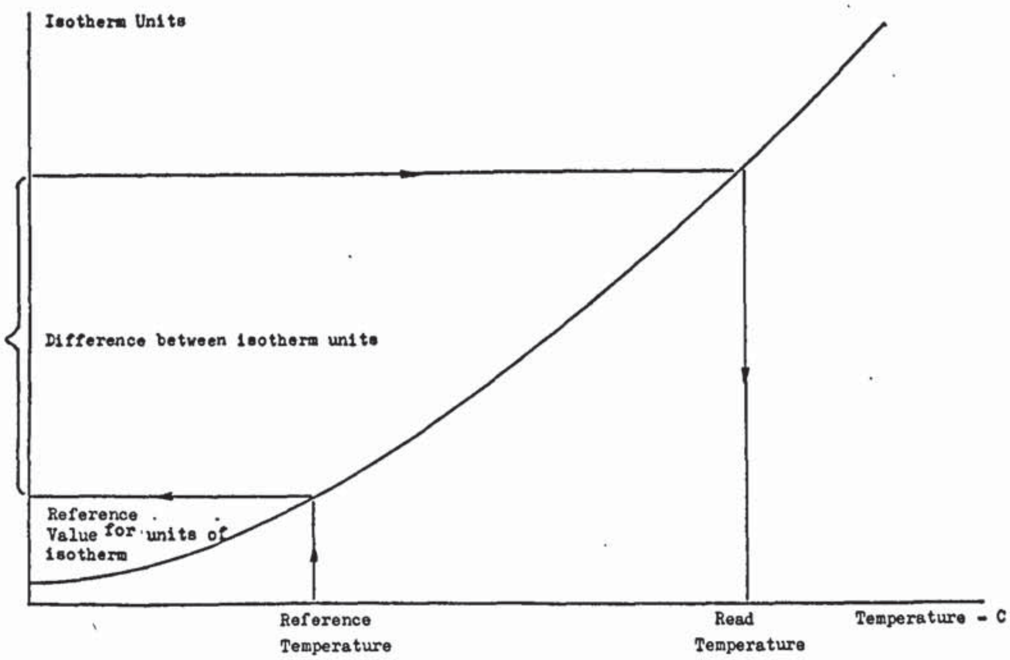
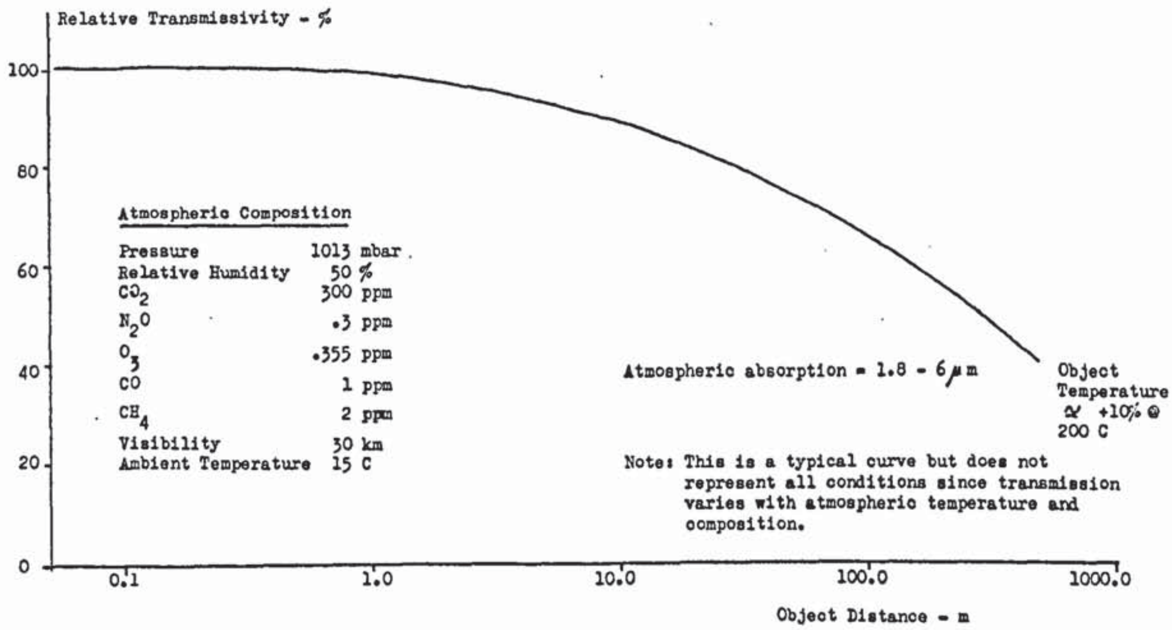


Figure 6.5.3 Correction Curve for Average Losses of IR During Transmission Over Distance



a. Isothermal-marker width: If the width is not taken into account when reading the bottom grey-scale, errors could result. Since marker-width increases to the left when varied with width control, the markers should always be read from the right-hand edges to obtain absolute temperature levels.

b. Lack of blackbody - simulating source: Certain details within the thermal picture can provide approximately known temperature levels which may be sufficient for purposes of reference. The background surface in a room, for example, can serve as a provisional temperature reference merely by obtaining the room-air temperature. Outside it is sometimes feasible to use the air itself as the reference. When examining the human body, an instant reference is provided by opening the mouth and breathing out gently ($\simeq 37^{o}C$).

c. Solar reflections: In the open sunlight, the risk of error from reflections can be great. While attempting temperature measurements, objects should be viewed from different angles to ensure that 'hot spot' indications are not caused by reflected sunlight or other radiation.

d. Non-blackbody radiators: The calibration curves are plotted for theoretically perfect radiation emitters (blackbody). Real objects will appear cooler than they actually are. Variation in emissivity between different details in the thermogram may contribute as much to isothermal contrast as do the object temperature differences themselves.

The emissivity of metals is low and, although it increases with temperature, a polished metal surface emits only a small fraction of the radiation emitted by a blackbody at the same temperature. This would appear cool even when hot to the touch. However, with a formation of an oxide layer on the surface, the emissivity of metals increases ten times or more (156).

A film of oil will also greatly increase the emissivity of any material to which it is applied. Likewise, oil based paints, regardless of colour, provide near-perfect emitting surfaces and true temperature rendition. Similarly the human skin is close to perfect emitter.

In general, visual colour is not a good indication of the ability of a material to emit infrared radiation. Snow is a good example, where the human eye, not sensitive to wavelengths beyond 0.75 μm, cannot sense conditions between 3 and 70 μm where the maximum spectral radiant emittance of snows occurs. If the eye did respond to 10 μm, snow would appear black.

e. Transmission path: The infrared transmission between an object and the IR camera is always $< 100\%$, due to the atmosphere attenuation over distances of several hundred metres, and losses in optical materials inserted between the object and the camera.

The presence of the tri-atomic gases such as CO_2, H_2O and O_3, introduces three influencial factors - attenuation, radiation and reflection. The reflection factor may be eliminated by using a reference at the same distance as the object; correction for reflection can be involved and laborious. Radiation from the gases, at the temperature levels and typical concentrations that occur in the atmosphere, can be for the most part ignored as the emissivity of gaseous substances is extremely low. Attenuation, however, depends upon humidity, pressure, gas concentration and temperature, which are difficult to correct. It suffices to use the correction curve (Figure 6.5.3) based on a typical atmospheric condition. At short distances, attenuation can be ignored.

f. Small objects: To the extent that the object surface to be measured is smaller, when projected on the camera picture plane, than the instantaneous field of view of the camera (e.g. 1.3 mrad for a 10° for lens), the temperature reading will be reduced in proportion (156).

g. Transparent objects: Glass or plastic presents a further problem in interpreting temperature. Transparent materials vary spectrally with wavelength. Many types of glass can appear black. Plastics can also be completely transparent in the wavelength band utilized by the camera. Without special selective infrared filtering, the instrument measures the temperature of what is behind the transparent object as well as the surface temperature.

6.5.3 IR Properties of Objects and Temperature Measurement

For objects departing significantly from the black body ideal, distortions occur in the grey-scale representation of the thermal image of the object. Temperature measurements based on the isotherm marker readouts alone will tend to produce faulty results unless proper allowance is made for the IR properties. Since most objects are essentially opaque in the infrared, the IR property of an object which is most encountered in thermography is the emissivity. Formulas have, therefore, been derived for calculating the true object temperature from the isotherm marker readouts, taking into account the emissivity, if this is known, or for calculating the emissivity if the temperature is known.

Such computation admittingly increases the degree of complication. Without, however, the true object temperature cannot be found with any accuracy. Similarly, without prior knowledge of the materials being viewed, emissivity and hence final temperature cannot be obtained. Derivations of the formulae can be found in the AGA operating manual (156). The total IR radiation given off by an object is composed of three different radiation components proportional to three factors, (Figure 6.5.4).

a. radiation emitted by the object as a result of object temperature To, proportion to the value of ϵ;
b. radiation reflected from the object as a result of ambient temperature of the surroundings Ta, proportional to ρ;
c. radiation transmitted through the object as a result of the background temperature Tb, proportional to τ.

When a small quantity of total radiation impinges on the IR detector it generates a complex signal which represents these independent functions. The response signal 'S' is given by:

$S = \epsilon.f(TO) + \rho.f(Ta) + f.(Tb)$

For non-transparent objects, $\tau = 0$, and $\rho = 1 - \epsilon$

$S = \epsilon.f(To) + (1-\epsilon).f(Ta)$

The Thermovision camera - signal vs blackbody - temperature (Figure 6.5.5) is exponential. For convenience, instead of signal voltages, arbitrary 'isothermal units' are used, which represent the ideal

Figure 6.5.4 The Three Independent Radiation Components

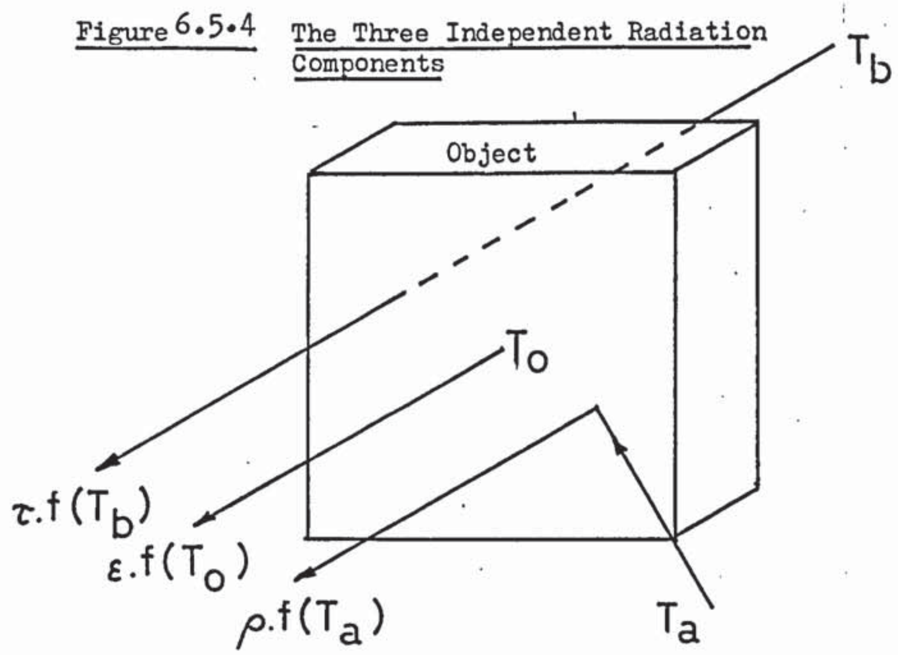
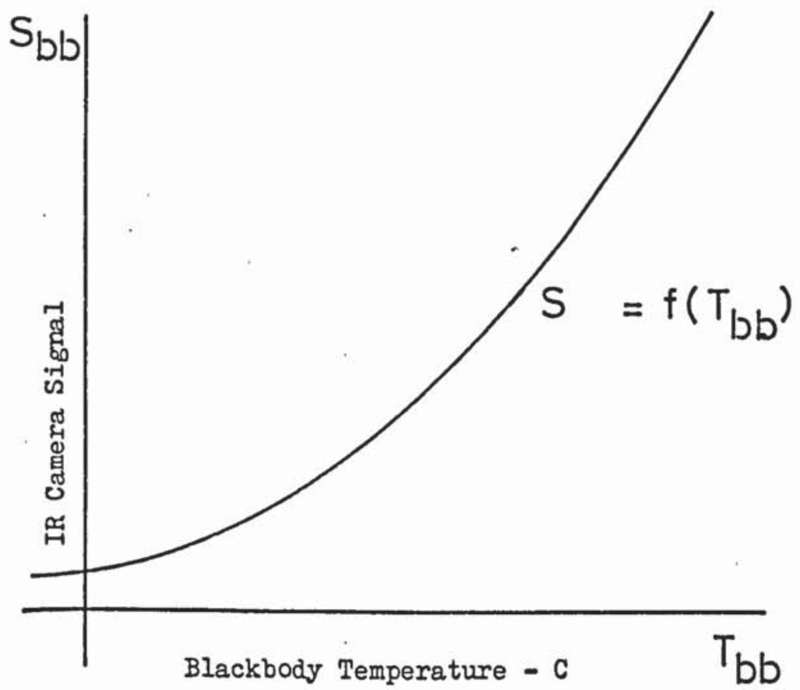


Figure 6.5.5 Thermovision Characteristic Curve of Camera Signal vs. Blackbody-Temperature Response



camera response to true object temperatures on the horizontal scale. It is important to discriminate between the blackbody - equivalent isotherm values (Sbb), read from the calibration charts, and the isothermal values, obtained from the thermal image by multiplying the isotherm marker positions by the sensitivity setting. Figure 6.5.6 shows the relation between the scales of the display, and temperatures (To and Tr) are related to the absolute isotherm levels Io and Ir by the Blackbody camera response curve. On the display, the thermal images of the object and reference sources are related to the image isotherm levels io and ir by the ϵo and ϵr curves, respectively. (Note image isotherm level = isotherm marker position x sensitivity). When measuring, accuracy is gained by choosing reference temperatures which give values for the image isotherm differences Δior which are as small as possible in order to minimise the temperature span of the thermogram.

The camera response signal can now be written by substituting I for f(T):

So = ϵo Io + (1-ϵo) Ia for object temperature

Sr = ϵs Ir + (1-ϵr) Ia for reference temperature

Visually these are displayed as isotherms for object and reference temperatures respectively. Isotherm levels are, therefore, equivalent to camera signal levels. Hence:

Δ ior = So - Sr

From these the equations summarised in Figure 6.5.6 can be derived. They are exact relations, valid for all values of ϵ and applicable for determining all values of T covered by the calibration charts.

Figure 6.5.6 Relationship Between the Scales of the Thermovision Display and the Calibration Charts

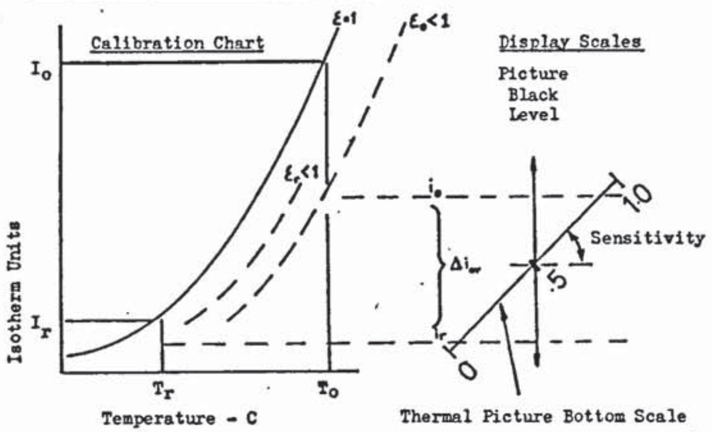


Figure 6.5.7 Formulas Used for Measurements Involving Emissivity (156)

T_o - object temperature

ε_o - object emissivity

T_r - reference temperature

ε_r - reference emissivity

T_a - ambient temperature ($\varepsilon_o = 1$)

I_o - absolute isotherm level for object temperature T_o read from the calibration charts

I_r - absolute isotherm level for the reference temperature T_r from the charts

I_a - absolute isotherm level for ambient temperature T_a from the charts

Δi_{or} - image isotherm difference $(i_o - i_r)$ observed between the thermal images of the object and reference temperatures

When both object and temperature reference emissivities can vary

$$I_o = \frac{\Delta i_{or}}{\varepsilon_o} + \frac{\varepsilon_r}{\varepsilon_o} I_r + \left(1 - \frac{\varepsilon_r}{\varepsilon_o}\right) I_a \qquad — 1$$

When the reference temperature source is a blackbody simulator ($\varepsilon_r \simeq 1$)

$$I_o = \frac{\Delta i_{or}}{\varepsilon_o} + \frac{I_r}{\varepsilon_o} + \left(1 - \frac{1}{\varepsilon_o}\right) I_a \qquad — 2$$

When the reference is the unfocused background temperature ($T_r = T_a$, $\varepsilon_r \simeq 1$)

$$I_o = \frac{\Delta i_{oa}}{\varepsilon_o} + I_a \qquad — 3$$

When the difference in temperature between two points on the same object is measured ($\varepsilon_r = \varepsilon_o$)

$$I_o = \frac{\Delta i_{or}}{\varepsilon_o} + I_r \qquad — 4$$

Determination of heat loss from surface temperature measurement

D Barnett: (158) 'Energy Conservation with Thermography' - L J Anderson

Ts - surface temperature - R
Ta - ambient temperature - R
ts - surface temperature - F
ta - ambient temperature - F
ε - emissivity
v - wind velocity - ft/min.

Radiative heat loss - Qr

$$Qr = 0.174\varepsilon\left|\left(\frac{Ts}{100}\right)^4 - \left(\frac{Ta}{100}\right)^4\right| \quad \text{Btu./ft}^2\text{.hr.}$$

Convective heat loss - Qc

$$Qc = 0.296\,(ts - ta)^{5/4}\sqrt{\frac{v + 68.9}{68.9}} \quad \text{Btu./ft}^2\text{.hr.}$$

Total heat loss - Qt

$$Qt = Qr + Qc \quad \text{Btu./ft}^2\text{.hr.}$$

6.5.4 Spectral Photometry

Absorptance, and hence emissivity, for some materials changes very rapidly with wavelength. Pronounced variation occurs with gases which have narrow absorption lines and bands in the infrared. The wavelengths at which these narrow bands occur are due to resonant frequencies,resulting from transitions between the energy levels of molecules and atoms composing the material. Where wavelengths of the IR radiation coincide with any of these resonant frequency wavelengths, absorption is high. Glass and plastics exert similar properties.

When measuring the temperature of IR transparent materials, it is necessary to restrict the wavelength range of the camera to a spectral band where IR absorption is high. In other words, within the spectral band utilized by the IR optics and detector, an absorption band must be located where IR transmission is virtually zero. A 'spectral filter' must then be found which will pass IR radiation emitted within the specific absorption band.

Plastics such as polyethylene, being almost totally transparent to IR radiation, has a narrow absorption peak,occuring at $3.43\mu m$, caused by the molecular carbonhydrogen bands (See Figure 6.5.8). At this wavelength, the temperature of thin films of plastic can be found using a 'Plastics measurement filter' (156).

Outdoor IR measurements are often influenced by reflected solar radiation,which consequently disturb remote temperature measurements. Filters may be used which transmit only the radiation which has wavelengths $> 3.5\mu m$, and consequently render negligible the influence of reflected high-intensity, short wavelength radiation from the sun with respect to thermal radiation from objects at ambient temperatures.

Transmission through glass is high for IR radiation of wavelengths $< 3 \mu m$, dropping off rapidly with increasing wavelength so as to be completely opaque for those greater than $> 4.5 \mu m$. The 'Glass measurement filter' must be used to measure glass temperatures. The effects of transmission and solar reflection in industrial surveys are important. Filters were not, however, available for use in the experiments carried out. Solar reflections were minimised by carrying out the remote sensing on dull days. The effects of transmission through roof lights and 'north lights' were minimised by the general dirty nature of the glass surfaces, most being covered with carbon black. Only well cleaned windows presented a problem.

6.6 Procedure and Interpretation

Following discussions with engineering management, proposals and procedures were prepared before each study (347) (348) (349). Examples of past work was reviewed to establish the intent of the survey. Reference here is given to the improvement to steam consumptions on Autoform (40.5 inch) Presses, Tyre 5 (88). Also reviewed were plant operations, equipment and metering, with special emphasis on energy flux movement within the factory. This was in agreement with the approaches practiced by C W Hurley and K G Kreider (157) in the USA.

A "walk-trough" with plant personnel or as in this case, previous "inhouse knowledge" of the operation, was believed necessary to select targets for scanning, so as to certify the capability of the equipment and to provide the background detail for the total site scan. Items such as tyre presses, mills, boilers, flues, autoclaves and other hot spots were noted. All maintenance problems and plant peculiarities were also recorded. Tyre 5 became an obvious department for close examination, on account of the already adequate monitoring of services supplied, its physical isolation from other buildings and operations, the relative effectiveness of energy use, (other departments could only be worse) and the facility for studying recent conservation actions.

With these established, the camera was set up and the equipment calibrated with reference temperature surface measurements. Wherever possible, measurement of surface temperatures in the field of view were taken using conventional means. Conventional photography was employed for identification and location of the thermal information. Hot spots were set to the top of the thermogram temperature range with the full range adjusted to include darker areas. It was apparent from the literature, both published by the manufacturers (156) (159) and previous researchers (157) (160), that optimal range, scale selection, and final interpretation would require considerable skill. The author, therefore, deemed it necessary to enlist the expertise of a colleague, Dr. R Williams, who was conversant with the procedures and the Dunlop equipment.

6.6.1 Formulating Results

The results displayed in Chapter VIII and IX were completed on the procedures clearly described by the manufacturer (156) and summarised in Section 6.5. Temperatures and consequent heat loss were calculated from the derived thermographic formulae and heat transfer theory (132) (155) (158). Evaluations of associated energy flows measured by conventional means were also made. Additional wind-speeds, assessment of cloud cover, ambient conditions etc. being included.

Even prior to investigation, it became increasingly evident that thermographic quantitative analysis could not be derived from a simple depression of the camera button. Additional critical measurements, other than those taken to verify the research findings, would be necessary. This introduced scepticism as to the potential success of the then newly established Aerial Surveys, resulting in their omission in this work.

6.6.2 Indirect Identification

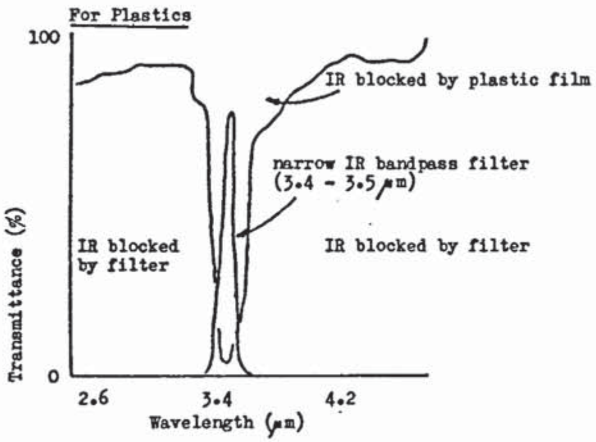
Thermography can be interpreted as a means of extending the normal visual identification process into the infrared regions of thermal radiation. At the time of the experiments, full understanding of the potential of thermography in the field of energy conservation was not wholly understood or appreciated.

However, it was possible to envisage a number of procedures whereby the location of the fault or loss could be predicted from symptoms. What is 'seen' by the camera is not necessarily the source of thermal loss! Some examples include:

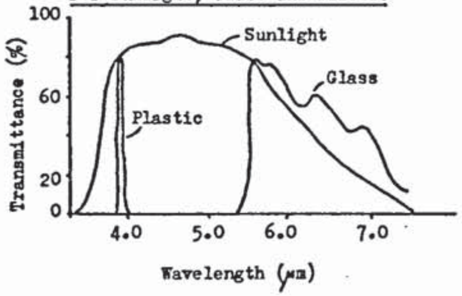
a. Air, heated by some source (machinery) will tend to rise into the roof area to escape through vents, windows or even doors. Such channelling could lead to a heating of the roof in an area far removed from the heat source. Interpretation of the thermogram must be made with care.

b. Stack flue gases of high temperature could indicate either boiler inefficiency or the need for heat exchange. This is

Figure 6.5.8 Standard IR Filters Available



Spectral absorption: "Cryovac" (0.025mm)



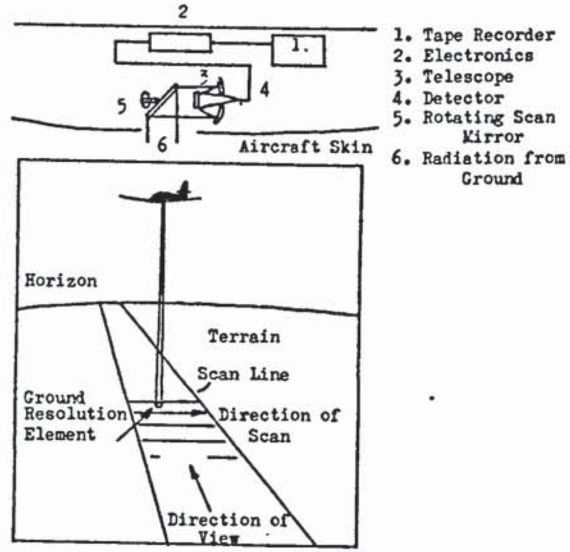
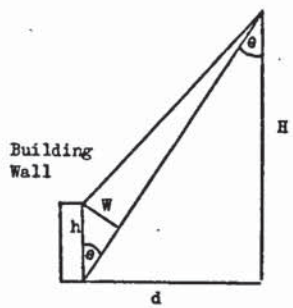


Figure 6.7.1 Airborne Multispectral Scanner Operation



$$W = h \sin \theta$$

$$= h \sin \left(\tan^{-1} \frac{d}{H}\right)$$

$$= \frac{hd}{H}$$

Figure 6.7.2 The Appearance of a Vertical Wall to the Scanner and the Apparent Height W of the Wall easily seen through the camera.

c. Radiators, hot pipes or machines will be identifiable through walls.

d. Hot spots in buildings or equipment may be the result of either poor insulation or additional heat released from a source beneath the outer skin.

e. Dark areas on thermograms taken inside buildings may indicate various forms of cold air infiltration through faulty lagging, draughts etc. (159)(160).

The present state of the art is such that it is necessary to build up a thermogram library for such effects. The National Swedish Institute for Materials Testing has already made a positive contribution towards this objective, albeit that the cases in question relate mostly to buildings. It was hoped that the work carried out at Fort Dunlop would contribute to such objectives.

6.7 Aerial Surveys

The potential benefits of Thermographic techniques in establishing energy loss through rapid homing into the point at which wastage is occuring are obvious. The alternative is to start at the other end and measure, continuously, subdivided flows using traditional means. For thermography the obvious point of commencement is a plan-view of the factory, building or town from the air. This could later be followed by closer defined investigation.

For many years, military and scientific purposes have used IR satellite photographs to monitor thermal patterns. At such height however, resolution is poor; a single point on a television screen representing 50 square yards minimum. This technique cannot, therefore, identify point sources. The alternatives include nocturnal aerial scanning or viewing from high buildings.

Energy release from buildings, whether these be industrial, commercial or domestic, is a function of the nature of the enclosure, thermostat setting, occupancy life style, equipment efficiency and heat recovery devices. The type and quantity of material used, the quality of construction, and certain design features can be identified using airbourne thermography. A variety of equipment is available for such studies. These include:

a. Texas Instruments B-310 radiometer (158) - Energy, received by the scanner, is focused on cryogenic-cooled detectors, converted to light through the use of a light-emitting diode, and by means of a mechanically-coupled recorder exposes the photographic film in a film magazine. The film is moved at a rate proportional to the velocity and height of the aircraft producing a continuous photographic record of the radiant energy detected.
b. AGA 680 Thermovision (158) - Using the conventional camera with an alternative power source and additional scanning mechanisms, successful aerial images have been obtained.
c. ERIM M-7 (158) - This consists of a multi-spectral, 12-channel scanner system capable of recording two thermal bands simultaneously (8.2-9.3 μm and 10.4 - 12.5 μm wavelengths). Figure 6.7.1 illustrates the operation of the line scanner. It is basically an optical telescope with its narrow field of view continuously re-directed by a spinning flat mirror, which provides a scan in a plane perpendicular to the direction of flight. Two cryogenically cooled radiation detectors in the focal plane of the

telescope convert the focused beam of filtered radiation to electrical signals, which are digitised for record on magnetic tape. Within the scanning cycle, the optics record two temperature references internal to the scanner. At a later stage, a continuous tone video image can be produced on a CRT - 70 mm film strip printer. At 450 m, a ground resolution of 1m can be obtained.

The Airbourne Multispectral Scanner provided the basis for the AERE Harwell Surveys, April 1978. The data, retrieved as levels of grey, were processed on a DEC PDP 11 computer and real image analysis software. In effect 256 grey levels could be produced. The theory involved is adequately reviewed by C D Rodrigues (163) and needs no deliberation here.

6.7.1 Interpretation of Results

Aerial data is interpreted using the various types of imagery- continuous tone images, indicating relative temperature difference by variations in contrast (grey tone) and black and white temperature slices. A major obstacle is emissivity variation and must be considered in analysis.

Quantitative evidence is provided by the temperature slice method. Past experience has shown that surface water and vegetated areas are generally warmer than roof surfaces and that the latter are generally colder than air temperatures on clear nights, due to the net transfer of heat by radiation to the cold sky. These are, however, only apparent temperatures. In producing images, it is assumed that emissivities of all surfaces are constant and near unity. In nature this is a fair assumption, most surfaces having emissivities $\geqslant 0.8$

(E Sampson and T W Wagner (158)). Correction must, however, be made for surfaces known to have low emissivity:- aluminium.

A further adverse anomaly is 'view factor'. Buildings recorded in aerial surveys have pitched rather than flat roofs, and receive radiation from nearby surrounding surfaces such as adjacent trees and buildings. These will require correction. The comments applicable to roof tops, also apply to vertical surfaces such as walls. Without additional ground thermographic studies, 'side' radiation can only be approximated, since the angle of incidence θ, shown in Figure 6.7.2 is often small. The 'view factor' effect presents a secondary problem.

At large distances or heights, correction will have to be made for attenuation of radiation through the atmosphere. AGA's calibration curve, given in Figure 6.5.3 gives an arbitrary correction (10% adjustment needed at 1000m).

Although a procedure for calculation of U - value of horizontal and vertical surfaces has been put forward (163), the level of confidence in the computation cannot be high due to the wide tolerances in assessing effective sky temperature, emissivity, view factor ect. Many additional measurements will still be needed.

6.7.2 Concluding Comment

Qualitative interpretation of roof-top losses appear relatively simple, straightforward and effective, even though this can be hampered by emissivity variation etc. In this context Aerial surveys provide meaningful results, especially in preparation for more detailed ground surveys. It is interesting to note that most research programmes have utilised the facility in this context.

Extreme care must, however, be used in determining losses from the sides of buildings, as apparent 'flare' may be due to as much to heat retention, by say concrete side-walks, as building loss.

Quantitative results are less certain. Several factors already outlined inhibit the widespread use of aerial thermography without additional measurement and assessment. W Hazard (158) emphasised that the heat loss ratings for aerial surveys were not quantitative. He also stated that ratings were subjective since they still depended on an interpreter's judgement.

Should quantitative measurement of some consequence be derived from aerial thermography, the following would be needed:

a. a knowledge of the buildings, operations, roof/wall materials etc.
b. additional ground and air measurement of surface temperatures emissivities, cloud cover, wind velocity, monitoring height etc.
c. additional ground thermographic surveys.
d. extensive computation for correction factors.

Such requirements defeat the basic objectives of thermography in providing a quick, simple, cheap but effective means of determining energy loss.

Aerial surveys are also comparatively expensive. Even without any quantitative calculations, computer simulation is time consuming. At the time the decision was made to pursue thermographic detection of heat loss, the evidence was such that even if an aerial survey was readily available cost would be prohibitive in the light of the gains thereof. Consequently, it was decided to pursue remote sensing using the Thermovision 680 camera mounted on a high building some 500 meters from the Fort Dunlop boundary. It was realised that some corrections would still need to be computed, but in the event of Dunlop possessing its own camera, this action was deemed the obvious option.

6.8 Summary of Objectives

The following aims and objectives have been summarised from the reports published for the commencement of the thermographic experiments (347) (348) (349) (164).

1. To derive an alternative procedure for the identification of energy misuse within the 'diffuse' category of British Industry; traditional means being expensive, difficult to implement and time consuming.
2. To establish the feasibility and validity of thermographic remote sensing techniques for the qualitative, and subsequent quantitative determination of temperature 'hot spots', and hence heat loss from plant, equipment, buildings and entire factory sites.
3. To relate the determined losses to energy inputs (thermal, electrical or otherwise) entering that plant, equipment, building or site, thus establishing the feasibility of using thermography to obtain an energy balance.
4. To validate the hypothesis that commencing with remote site surveys, energy loss could be identified and determined from successive stage focusing or 'homing in' on the source.
5. To establish the potential of thermography for detecting alterations, improvements or adverse changes in energy use

brought about by conservation actions, production alterations or inefficienty.

6. To compile a library for future reference of thermographic records showing the effects and behavioural patterns of heat loss and/or 'cold-infiltration' with respect to plant and buildings.

Thermography Stage I was designed to investigate heat loss from specified plant and equipment used in the production of tyres. Employment of conventional measuring devices was needed to validate results.

Thermography Stage II was designed to evaluate heat distribution in buildings and energy transmission networks, including remote sensing of the whole site from nearby high buildings. These incorporated additional measurements of energy inputs to and some outputs from the 'systems' under examination.

Prior to the thermography experiments, the principles of remote sensing techniques were reviewed using the principle of photographic snow-melt studies of the Fort Dunlop factory roof.

This, the thermographic results, and ultimate conclusions are given in the following three chapters.

CHAPTER VII

STAGE I - SNOW STUDY

7.1 Chapter Preview

The ensuing paragraphs report a study of heat loss from buildings on the Fort Dunlop site using the simple basic criteria of observing snow-melt patterns (346). Such a method of heat loss detection may be an effective, qualitative means of determining areas of high energy use, consequential waste, and possible conservation potential. Pictures of snow covered rooftops, taken from high buildings, clearly show the three modes of heat loss: convection, conduction and radiation.

The chapter argues the potential of such a method, the limitations and advantages being discussed in relation to alternative methods. Scope for future work is apparent; possibilities are presented at the end of the chapter.

7.2 Objectives and Requirements

For many 'diffuse' users excessive metering is not economic, feasible, is complex and can lead to inaccuracy through error. Simple techniques for determining losses are, therefore, needed. Amongst those discussed in Chapter 4 is the study of snow-melt on factory rooftops.

The aim of this exercise was to demonstrate that by photographing melting snow on rooftops, there existed a simple qualitative method of determining heat loss. In addition, it was hoped that the results of the study would reflect possible areas for improvement within Fort Dunlop.

7.2.1. Requirements

a. A light snow-fall with little wind - Heavy falls assisted by wind effects tend to produce uneven distribution through drifting, and too rapid an accumulation of snow to permit identification of the melt.

b. A high protected point from which to take photographs - A room at the top of a building is ideal.

c. Photographic equipment, incorporating both a wide angle and telephoto lenses - For panoramic scanning, a tripod should be used.

d. An appreciation of the layout of the site, the equipment and operation functions within the buildings, and the structure and materials used in buildings.

e. Suitable light intensity and clarity - Swirling snow can effect clarity and consequential interpretation of the photograph. The most suitable time would be after a snow storm of short duration and in bright light.

f. A logging system for each photograph taken; records being made of observed criteria appertaining to that photograph.

7.2.2. Assumptions

a. The accumulation of snow was evenly distributed on all roof and skylight surfaces whether these be flat or pitched.

b. The degree of snow-melt was proportional to the heat released from that part of the building.

c. The degree of rate of snow-melt in one building was consistent with that in another; both having identical 'U' valves.

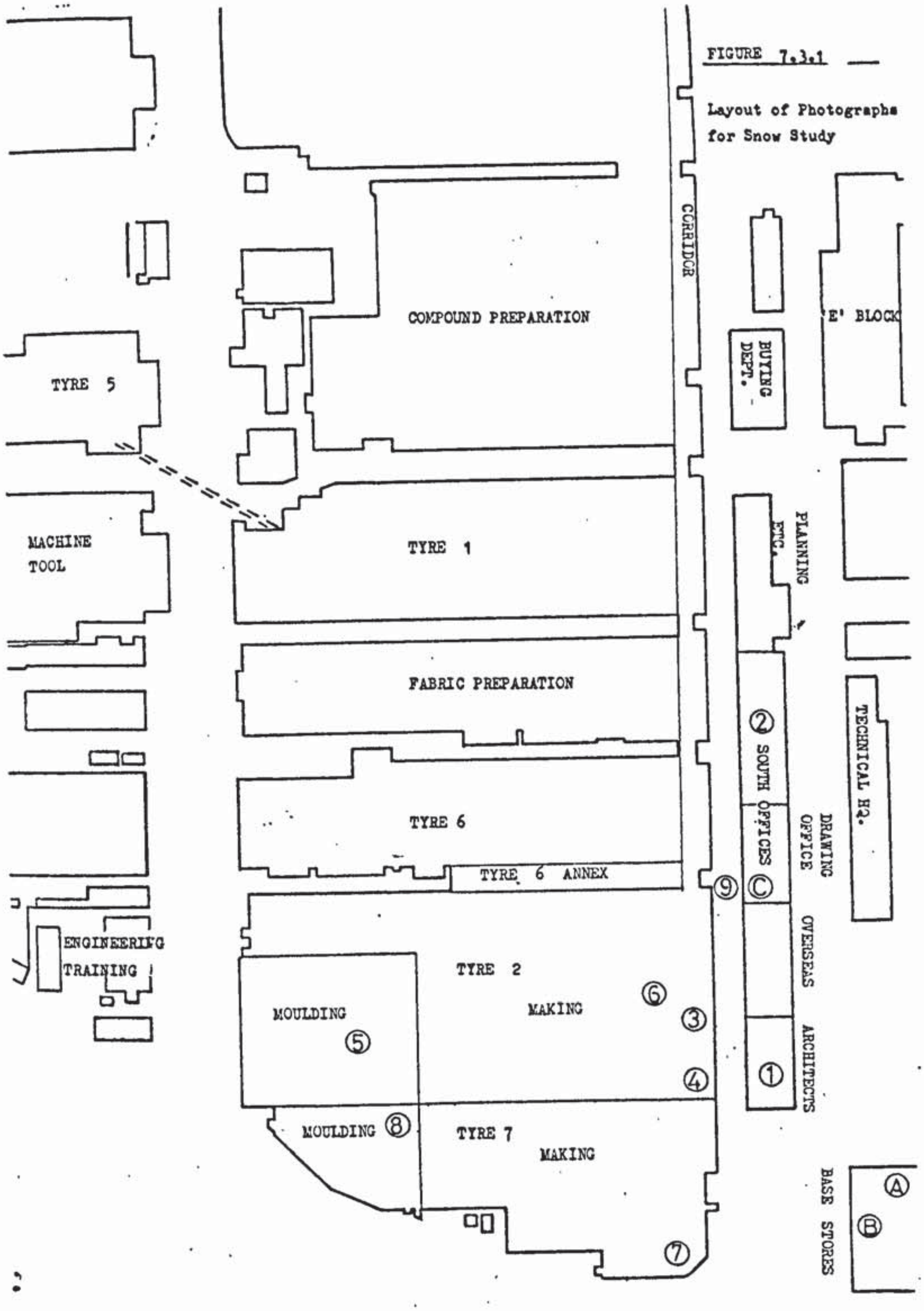
d. The degree of snow-melt reflected similar rates of heat loss for any of the three modes of heat transfer.

7.3 Experimental Procedure

The study was carried out at Fort Dunlop on Thursday 13th January, 1977, during the hours of 1400 to 1530. The photographs were taken from the top floor of the Base Stores building, situated at the southern end of the factory; and from the first floor of the South Offices. Approximate positions of these points are shown as a letter in figure 7.3.1. The photographs taken from each point are indicated by a number preceded by the letter appertaining to that position.

FIGURE 7.3.1

Layout of Photographs for Snow Study



The snow fall appeared heavier than the ideal and, due to frequent wind gusts, ended in slight drifting. Apart from slight nonuniformity in thickness, the larger accumulation limited the consequential analysis to identification of large heat losses only; lesser wastage failed to show up on the photographs. A list of general areas photographed is given in table 7.3.2.

The camera used was a 35mm SLR Petri TTL with both 50mm and 200mm lenses.

7.4 Results (See Plates 7A, 7B and 7C)

Probably the most surprising and significant results obtained from the study of the photographs was the successful pictorial portrait of all three forms of heat transfer. The effects of radiation transmission through sky-lights and windows can be seen as areas of melt along the length of the glass (see photographs A1 and A2 of South Offices). Convective losses from roof vents are clearly identified in photographs A3 and B6 of Tyre 2 roof. The majority of the remaining dark patches represent conductive loss.

In general, greater losses in the heat distribution pattern are indicated by darker patches. Care must be exercised in studying 'close-up' photographs, however, since vertical surfaces are not easily distinguishable from horizontal or inclined planes. Snow will not easily adhere to vertical surfaces and these will appear darker.

TABLE 7.3.2

List of Photographs.

Letters signify the position from which the photograph was taken.
Numbers signify the general area and subject of the photograph.

A 1.	Overseas and Architects Departments - South Offices.	
A 2.	Overseas, Equipment and Planning Departments - South Offices.	
A 3.	Tyre 2 - Making.	
B 4.	Tyre 2 - Making.	
B 5.	Tyre 2 - Moulding.	Close up.
B 6.	Tyre 2 - Making.	Close up.
B 7.	Tyre 7 -	Close up.
B 8.	Tyre 2 and Tyre 7 - Moulding.	Close up.
C 9.	Drain exterior Tyre 6 - Central Drive.	Close up.

A1

A2

PLATE 7A

A3

B4

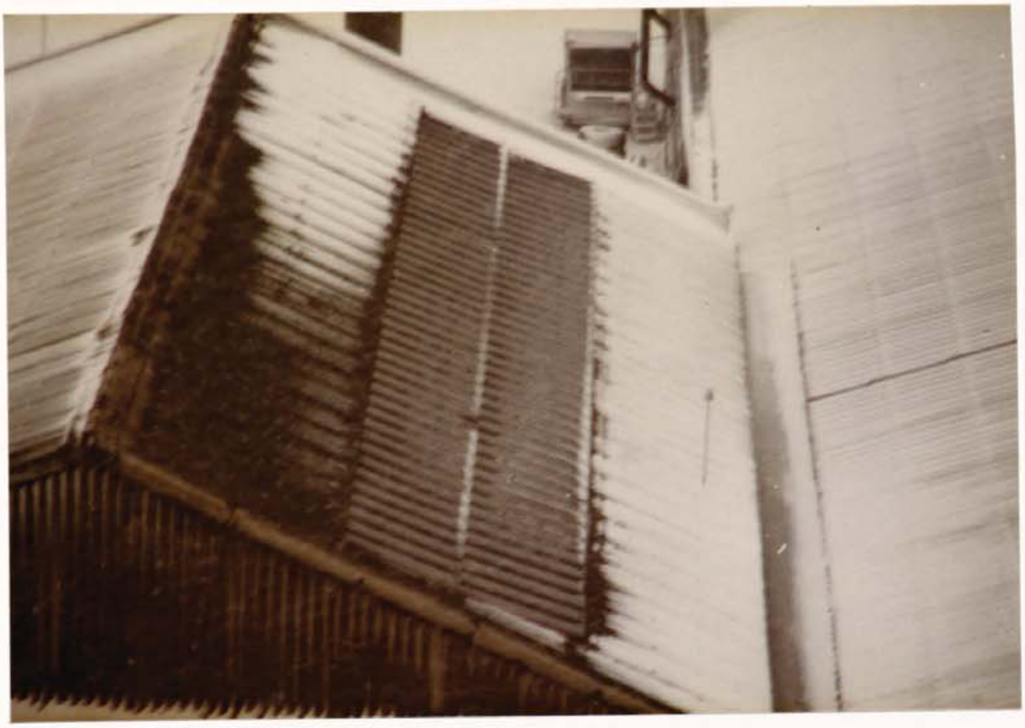
PLATE 7B

B5

B6

PLATE 7C

B7



B8

PLATE 7D

C9

PLATE 7E

Although inclined planes will tend to have less accumulation than horizontal planes, it is assumed the variation is small. However, comparison of the two is avoided as much as possible.

Many of the photographs indicate common features. However, each photograph is studied in turn, relevant points being noted.

7.4.1. Photograph A1

General Observations: Differences in whiteness intensity indicated a greater accumulation of snow on the roof of South Offices than on that of the main part of the Factory. This was likely to result from greater roof losses, due to contrasts in construction materials and higher temperatures on the shop-floor. The effect of roof inclination may have also been significant. Evidence that losses were greater from the factory is substantiated by the darker tone of the flat roof sections along the Central Drive.

Specific Points:

a. Radiation and conduction losses from skylights in South Offices were clearly indicated.
b. There were more pronounced losses from open-space areas, i.e. the Overseas Department. Losses were also greater from the Architects' Department's open-plan office than from the stairwell, as indicated by melt on the central sky-light.
c. Convective heat loss was shown from vents in the roof of Tyre 2 and Architects' Department.

d. There was less heat loss from sky-lights in the flat roofed areas of the factory along Central Drive.

e. Additional heat loss from the Architects' Department could be identified as two separate dark patches.

f. Greater radiation losses were apparent through windows of the Architects' and Overseas Technical than the Overseas Departments; shown as degree of melt on window sills.

g. Open window was in evidence in Overseas Technical Department.

h. Greater loss was identified from Tyre 2 - Making than Tyre 6 - Making with respect to both conduction and convection.

i. There were clear losses from the two vents in Tyre 2 - Making.

j. There was a tendency for losses to be greatest at the apex and top corners of the roof.

k. Larger heat loss was shown in one section of Tyre 6 - Making, where the roof joins the wall.

l. Note was also taken of the large number of individual extractor fans in South Offices; showing as black objects in windows.

7.4.2. <u>Photograph A2</u>

<u>General Observations</u>: This was similar in composition to A1, but extends to and includes the north end of the factory. Once again greater losses were apparent from the factory roof.

Specific Points:

a. Heavy radiation and conduction losses were clearly indicated from South Offices' sky-lights, in particular the north end and Planning Department. The dual sky-lights over the Equipment Department provided large losses.

b. Convection losses were apparent from roof vents in Tyre 6 - Making.

c. Conduction losses were apparent from the joint between roof and wall in Tyre 6 - Making, and through the sky-light (F.P.D.)

d. Heavy conduction losses were in evidence from both the lower and raised roofs of F.P.D., in particular sky-lights. This example showed how heat loss tends to be concentrated in the corners of buildings where roof meets wall.

e. Heat losses from Tyre 1 and the C.P.D. appeared less than those from the south side of the factory.

f. There was less loss from the Buying Department due to the effects of a ceiling.

g. Losses from office windows were greatest in the Architects' and Overseas Technical Departments, followed by the Overseas and Equipment Departments. Those from ground floor offices were much reduced.

h. Losses from flat roof areas were greater for the factory than South Offices.

7.4.3. Photograph A3

General Observations: This photograph showed the general heat loss from Tyre 2 - Making Section. Factory losses appeared once again to be significantly greater than the South Offices.

Specific Points:

a. Identical to A1, this photograph of the Architects' Department highlighted the three modes of heat transfer more clearly. Of particular interest were radiation and convection losses from sky-lights, losses being smaller from that covering the stair-well.

b. Convection losses from Tyre 2 vents tend to be greater at the Central Drive end of the building. The two examples in the centres of greatest melt (see B6) gave off sufficient heat to produce an actual dry area. Taller vents tended not to show convection loss as clearly. Radiative and conductive modes might even have prevailed.

c. Conduction losses through the roof were clearly identified as brown patches or grey shades. Of the two tall vents, the higher degree of melt on the cap of the right hand case indicated the hotter air flow. Conductive losses appeared greater over the making than the moulding sections. This could have been the product of hot moulding air being ducted to atmosphere through louvres.

d. Losses through conduction also appeared greatest at the joints in the roof, followed by the apex, and finally the walls.

e. Losses from sky-lights in Tyre 2 Making were considerably less than South Offices.

f. Heavy steam atmospheric discharge from Tyre 6 - Moulding were noted, (top of picture).

7.4.4 Photograph B4

General Observations: The overall heat loss from Tyre 2 was greatest near the Central Drive. Amongst other things, this might have been explained by a poorer degree of insulation.

Specific Points:

a. There was clear indication of radiation and convective loss from Tyre 2 sky-lights, closed louvres and roof vents.

b. Conduction losses from Tyre 7 and Tyre 2 - Making appeared large; possibly a consequence of internal air movement.

c. The Central Drive drain was hotter than the surrounding areas, probably a product of hot water discharge from basins etc. (see C9).

d. Losses were noted at both the points where roofing sections were connected (left of picture) and in the centre of the sections (right of picture). The former was more likely convective; the latter is conductive.

7.4.5. Photograph B5

General Observations: Here heat loss from Sections of Tyre 2 Moulding roof appeared greater than that from the making section. In contrast to B4, large areas of melted snow could be identified between the louvres.

Specific Points:

a. Hot air dispersion was greater from some vents than others. Intensity of heat loss was reflected by the degree of melt near Tyre 2 louvres. The large heat release ducted through the louvres could be identified.

b. Heavy clouds of steam from Tyre 2 moulding obscured other areas of snow melt.

c. Conductive losses for the Training Centre and Machine Tool were much reduced. In the case of the latter, however, loss near the central raised section was noticeable. These probably constituted a combination of convection, from open windows, and radiation through the glass.

d. Convective losses from the small inverted vent (middle left of picture) could be compared with the adjacent example.

7.4.6. Photograph B6

General Observations: A clear contrast of low to high heat loss could be seen here from the comparison of the unmelted snow area (upper left); to the semi-melted streaky areas, where losses were greatest in the centre of the roofing sections; to the wet melted area; and finally to the dry roofing circling the ventilator caps. Further investigation was suggested.

Specific Points:

a. Sky-lights on the flat roof area at the bottom of the picture had relatively high heat loss.

b. Conductive loss from the joint of the vent (top right) with the roof indicated the dissipation at the base and from the sides. By the time the air passed through the cap it was relatively cool, indicated by the lack of melt on the cap itself compared with the vents on the left. It was also possible that the joint of vent to roof leaked hot air from the building interior.

c. The high convective heat loss from the two large ventilators was clear.

7.4.7. Photograph B7

General Observation: Heat loss from this Tyre 7 roof was greater than that from neighbouring areas.

Specific Points:

a. The conductive losses from the sky-lights were large.

b. The losses tended to be greatest at the apex and towards the nearest corner. The patterns of melt were noted and compared with previous examples, this being a poorly insulated roof.

c. Further convective losses occurred at the overlap of the two roofs, which may have been slightly misleading since this area was better protected from snow accumulation and may also have been wetter due to drainage from both roofs.

7.4.8. Photograph B8

General Observations: This was similar to B5 but covered more of Tyre 7 - Moulding (left). Heat losses between louvres were clearly seen; Tyre 7 appearing to be hotter.

Specific Points:

a. Steam losses were extensive through atmospheric vents and leaks in both Tyres 2 and 7 (right and left respectively). These tended to obscure the pattern of melt.

b. Non-uniformity of snow accumulation on Tyre 7 roof, particularly in the centre of the roofing panels, indicated conductive losses.

c. Extensive convective activity from Tyre 7 and Tyre 2 moulding gave large melt areas (centre).

7.4.9. Photograph C9

Specific Points:

a. Heat was lost by both convection and conduction from the drain cover. The melt by conduction on top of the cover was greater than the spread of convective losses towards the wall.

b. For this to occur, there must have been a relatively large heat source, either hot water or condensate.

7.5. Consequential Findings and Recommendations

Subsequent to the results obtained from the photographic study, investigations of specific areas and anomalies were made. These are briefly outlined in the following paragraphs.

7.5.1. South Offices and Architects' Department

a. The apparent high heat level in the Building, as shown by the melt on and near sky-lights (A1 and A2) was a consequence of heating coils in the roof space. Whilst roof conductive loss appeared larger in the factory, comparable sky-light losses were less. South Offices were, therefore, assumed to be hotter. This might have been necessary with employees not being physically active. However, it was suggested that temperatures could still be lowered. Evidence was substantiated by the need to open windows. In general, the first floor and Architects' Department were hotter than offices below. There was indication of need for greater control and avoidance of the positioning of heating coils under sky-lights.

b. The effectiveness of isolating heating in stair-wells was evident within the Architects' Department (A3), where melt on sky-lights was reduced over the well. It is not necessary to heat stair-wells or corridors; these will absorb the natural convection and conduction from offices. Building segregation through double-door entrances, office doors and stair-well doors is essential. Fortunately, fire door specifications have helped to improve this.

c. Losses from the Architects' roof vent resulted from convection within the heating services shaft running up from the ground floor. This formed an effective chimney. Poorly sealed or open access doors make for large convective flow. Avoidance of accumulated moisture on the walls in the shaft is necessary, but it was questionable whether a vent was required and whether the pipe insulation of both hot and cold systems could be improved.

d. Photograph A3 indicated suspected flaws in the fibre-glass roof insulation of the Architects' building. Installation of insulation must be to standard since removal of the false ceiling to rectify a fault is both time consuming and expensive.

e. The Planning Department Building is only partially covered by a ceiling, the open plan area being open to the pitched uninsulated roof. The heating relies on coils in the apex of the roof, the heat from which dissipates by conduction and through badly fitting or open sky-lights. These coils should be removed and the heating system redesigned; incorporating a ceiling over the entire area(including the corridor) together with fibre-glass insulation. Evidence of loss was shown in A2, contrast being made with the ceiling plus insulation of the Buying Department roof.

7.5.2. Factory

a. In general the factory roof insulation could be improved, (i.e. the high degree of snow melt in the making sections). This, however, would be expensive and might not be feasible without additional control of heating levels, integrated ventilation, or reduction of heat from plant and equipment. Government grants are available for such proposals. In addition, collection of heat in the pitched roof, the degree of general ventilation and the effects of the north-lights, often with open windows and extractor fans, gave heavy loss. Improvement to the structure is also expensive but inevitable.

b. There were countless examples of general ventilation in Tyres 2, 7 and 6; F.P.D. and C.P.D., the heat losses being substantial (see B6). General air extraction is not sound practice and should be minimised; preference being shown for controlled localised systems with heat exchange. It was questionable whether the extraction from Tyre 2 banner general work area, and the mill (A3 and B6) was essential.

c. There appeared a general increase in losses over Tyre 2 and 7 making sections. In contrast to Tyre 6 and other departments, these were not partitioned from the main corridor; facilitating large air movement. They also housed the steam control stations for Base Stores and 'B' Block. This accounted for the apparent heavy losses through the roof in B4. The migration of heated air through all shop areas causes draughts and losses. Specific areas, such as making, corridors, moulding etc. should be partitioned and isolated. Exterior doors (B4) should also be kept closed.

d. Heat rises to the apex of a roof. If there is no effective air seal, convection to atmosphere will take place due to the chimney effect. This was clearly shown in Tyre 6 Annexe, where heat from the mill line and space heating was lost between the roof and the corridor wall (A2). In the case of B7, space heating mains and coils under the low roof in front of the raised pitched section, convected heat to the apex. It should be noted that this roof has no insulation, and a large percentage comprises sky-light area. Losses were, therefore, high.

Convective heat can be recovered from the apex and blown to the floor provided the level of fumes is acceptable.

e. Heat was lost from the inadequate joint between the vent and Tyre 2 roof (B6). Care must be exercised during installation of ducting.

f. Raised roof sections, such as those in F.P.D., Tyre 6 and Machine Tool, require much greater space heating, and have high ground to roof temperature gradients. Open windows in the upper sections caused convective loss through the chimney effect. If high roofs are necessary, the upper sections should not be made of glass with opening windows. Photographs A2 and B5 demonstrated the extent of the losses in F.P.D. and Machine Tool, where heat usage should have been less.

g. C.P.D. and Tyre 1 showed less conductive heat loss. These departments do not have large thermal usage for moulding activities. This demonstrated the point that making sections should be segregated from press areas to reduce air movement and draughts.

h. Ventilation from presses was mostly through louvres and small ducts (B5 and B8). This represented a large heat loss, which could be used through heat exchange or direct ducting for space heating in the making areas. Once isolated a moulding area could be controlled for both temperatures and air purity. Insulation of the roof might then pay dividends. It should be noted, however, that even if louvres are closed, they only form a single roof skin, which does not completely seal and has high conductive loss.

This was demonstrated in Tyre 7 making area (B4) where there was noticeable melt.

i. Heat loss down drains was severe (B4 and C9). This results from hot water basin drainage (could be reduced in temperature or flow but not totally avoided) or from steam and condensate loss into the system.

j. Heavy steam loss, both live, exhaust and flash were in evidence in Tyre 7, 2 and 6 (A3, B5 and B8). Maintenance, redesign and improved operation might be the answers.

7.5.3. General

The whole question of ventilation is raised here. Is it really necessary? Can it be localised? Can the heat be re-used? Integrated ventilation is of course expensive, but in conjunction with requirements for improvements in air purity there is a case. The removal of general extractor fans and vents in both the factory and in office blocks must be considered. Similarly, areas with high thermal usage should be isolated. Finally, employees should be dissuaded from opening windows if a room is too hot. Many of these points are consolidated in the need for greater control.

The use of sky-lights must also be discouraged due to both high conductive and convective loss. See Table 7.5.1. It is cost effective to seal off sky-lights with a good insulation material and to put in artificial lighting. The emphasis must be towards lower, insulated ceilings and well insulated roofs, with all windows and louvres sealed.

TABLE 7.5.1

U Values of Some Roofing Materials.

		Approximate U Values W / m^2 °C
1.	Asphalt / Concrete or Timber	1.8 to 3.4
2.	Asphalt / Concrete with Fibreglass Insulation	max. 0.61
3.	Tiles / Roofing Felt	1.4 to 1.6
4.	Corrugated Asbestos - Cement Sheeting	5.3 to 7.2
5.	Skylight - Ventilated & / or Unventilated	5.7 to 9.9
6.	Corrugated Metal	3.3 to 8.1

Source I.H.V.E. Guide

7.6. Apparent Limitations and Advantages

Singularly, the most obvious limitation is the restriction of this method to qualitative analysis only. Whilst in theory, the rate of melt is proportional to the rate of heat loss, in practice difficulties arise in attempting a quantitative dimension:

a. the snow is never evenly distributed;

b. the temperature may vary;

c. the quantity of snow falling is not easily measured;

d. the melt may be influenced by the micro climate;

e. the heat absorbed by any re-vapourisation or sensible heat cannot be estimated.

Having assumed a constant fall rate, uniform distribution, a know temperature, and total conversion to only water, it is possible to collect the melt and measure the temperature; thus giving the heat loss for individual buildings. This would still not account for losses through vents etc.

It may be argued that heat loss in an obvious wet, or even dry area as shown in B6, can be related to the rate of snow fall and the proportions of the melt. Table 7.6.1 attempts such a calculation.

Assuming qualitative analysis is possible, other limitations still prevail.

a. Unless the roof is flat or the photograph is of a plan view, only one roof surface is seen. In this case, the heavy losses from the north-lights were not viewed.

TABLE 7.6.1

Calculation of Heat Loss from the Two Vents Shown in Photograph B 6.

Dimensions (Approx.)

Inner Circle (Dry)	=	3m dia.	=	7.1 m^2
Outer Circle (Wet)	=	8.5m dia.	=	49.6 m^2

Rate of Snow Fall (for 13th. Jan. 1977, 1400 to 1530 hrs.)

Accumulation	15	mm / hr
Natural Melt (est.)	15	mm / hr
Total Fall	30	mm / hr

Temperature = 0 °C

Density of Snow (est.) = 400 kg / m^3

Approximate Volume of Snow Falling on Area

Inner Dry Circle	=	0.21 m^3 / hr
Outer Wet Circle	=	1.49 m^3 / hr

Approximate Mass of Snow Falling on Area

Inner Dry Circle	=	84.0 kg / hr
Outer Wet Circle	=	59.6 kg / hr

Latent Heat

Fusion	=	333.7 kJ / kg
Vaporisation + Fusion	=	333.9 kJ / kg

Heat Loss

Inner Dry Circle	=	28 M J / hr
Outer Wet Circle	=	199 M J / hr
Total	=	227 M J / hr
	(=	2.16 Th / hr)

b. Inclined planes may produce anomalies when compared with flat surfaces due to variation in accumulation. Vertical or near vertical surfaces cannot be used at all.

c. Areas may be subjected to obstructions to snow fall (i.e. roof overhang).

d. Drifting is common.

e. Geographical location may influence accumulation pattern.

f. Dark patches may be due to the wetting of snow by factory water loss, accumulation of melt in gutters or simply through poor photographic reproduction. The effectiveness of the photograph showing distant objects will depend on light attenuation. Telephoto lenses are useful.

g. Convective losses can only be located if the air/gas flow impinges on the roof surface or if the snow melts on the ventilator cap. Difficulties will arise with higher stacks,unless the temperature is sufficient to melt the snow,leaving a dark circle on the roof at the exit point.

Reflecting the objectives of this exercise, the usefulness of this technique and its true value to analysis of energy loss is unquestionable. With the proviso that there are deficiencies, the method reflects success in qualitative investigation. The analysis is simple, uncostly, easy to conduct and gives comparitative and valid results. Even if it were not possible, due to lack of quantitative evidence, to commission specific conservation actions from these results, clear indication is given as to where further investigations might be made.

Unlike the quantitative analyses of thermographic procedures, as described in Chapter VIII and IX, certain points favour this simple technique.

a. In contrast to thermography, through review of patterns of snow melt in relation to other physical criteria, it is possible to identify all three modes of heat transfer.

b. Direct identification of convective loss through horizontal surface and impinging vents is assured. Indirect analysis is also possible through observation of convective behavioural patterns (i.e. molten snow on vent caps).

c. Patterns of melt often reflect modes of loss not directly associated with the example in view. Heated drain covers, for example, may offer proof of leaking valves, passing traps or hot water loss.

d. General photography also picks up proof of standard losses through steam leaks, open-door, windows, louvres etc., and records these permanently.

e. Finally, unlike, thermography, this technique has the advantage of identifying actual heat loss as opposed to simply measuring temperature; albeit that quantitative analysis is perhaps a little ambitious.

However, there is still the need to measure actual heat loss. Similarly, it is not possible to cover plant and equipment with snow. Neither is it possible to differentiate between very hot surfaces by a series of degrees.

It was, therefore, necessary to carry out investigations using thermographic techniques.

7.7 Future Work in Simple Methods

One major drawback is the availability of a suitable snowfall. In the Midland region, for example, this is inconsistent and often inadequate (an average of 1-5 feet a year). Outside the reaches of thermography, it would be useful to have some alternative to the melting-snow technique.

When light reflects obliquely from a surface, it becomes linearly polarized in a plane parallel to the reflecting surface. The degree of polarization depends on the angle of reflection. Surfaces of non-dielectric materials (principally polished metals) have little plane polarizing effect. Diffusing surfaces, which present no specular reflection, do not polarize, but most surfaces do reflect linear polarized 'glare' light. A linear polarizer,with axis crossed to reflected polarized 'glare' light, will absorb this, thus enhancing perception of the scene.

Polaroid polarizing sunglasses are well known and are particularly effective on water. Airport control towers, pilot house windows and ocean liner windows are equipped with linear polarizers for light control. Polarizers can be used to discriminate between reflected light and 'Rayleigh - Scattered Light', for means of increasing photographic contrast between clouds and blue sky. (146). It is possible that extension of this phenomenon to the measurement or analysis of reflected light from wet and dry surfaces will provide information as to degrees of wetness.

The average rainfall in this country is consistent throughout the year. Rooftops are continually being wetted. If it were possible to measure the degree of wetness, or more to the point the extent of dryness, it would be feasible to detect heat loss using the same principle as the snow method. The procedure envisaged would involve two photographs; the first through a polarized filter and the second without. Comparison of the two photographs would then reveal the dryer areas and consequential loss.

Whether quantitative measurement of losses was possible would remain to be seen. Certainly the rate of rain-fall can be more easily measured and consequential evaporation noted.

It is far from the purpose of this thesis to discuss the theory of polarization nor to extend this thinking any further. It suffices to reflect the distinct possibility of such methods, whether use be made of either linear, circular or elliptical polarization, and to emphasise its credibility for future work.

CHAPTER VIII

THERMOGRAPHY EXPERIMENTS - STAGE 'THERMOGRAPHY I'

8.1 Chapter Preview

Thermography has been described as one possible solution to the present inadequate predicament as a diffuse site. Through the qualitative and quantitative detection of heat loss, industry would obviously enhance its efforts to conserve its energy resources. The use of Thermography may, therefore, offer a quick way of identifying and evaluating the potential areas for improvement.

This chapter reports the experimental procedure used, the results obtained and the conclusions drawn in evaluating the potential for Thermography within industrial energy conservation operations.

8.2 Objectives (347)

a. To investigate the practical feasibility of the use of Thermographic techniques for the qualitative assessment of thermal efficiency and heat loss from the standard industrial plant and equipment used in the production of tyres.

b. To assess the viability of the technique in producing quantitative values for such measurements.

c. To establish the possibility of analysing changes or improvements in patterns of energy use brought about by alterations in production operation, plant failures or conservation actions, normally monitored by traditional metering.

d. To estimate the potential scope for Thermography in diffuse industries.

e. To carry out each investigation without any adverse obstruction to normal production activities.

The following experiments were selected to fulfil these aims.

8.2.1 Experiments Selected

a. Effectiveness of Lagging on Pipes - Investigation was made of heat dissipation through various types of pipe insulation under suitably controlled conditions.

b. Identification of Poor Housekeeping - Examples of poor housekeeping, such as lack of insulation, steam discharges etc., were investigated.

c. Identification of Material Failure - Pipework and flanges were studied to establish irregularity in material composition and welding failure.

d. Detection of Steam Trap and Valve Malfunction - Studies were made of operation of steam traps, diaphragm valves and stop cocks to establish the state of operation and any malfunction.

e. Assessment of Possible Control of Production Operations - Study was made of the heat build-up in rubber during milling operations.

f. Investigation of Equipment Operation for Technical Design - Investigations were made of temperature differentials across moulding surfaces.

g. Analysis of Improved Equipment Performances - Studies were made of two similar tyre presses, one having additional lagging.

8.3. Experimental Specification

Date: Friday 18th and Monday 21st February and Monday 4th July 1977.

Location: All experiments were carried out within the confines of Tyre 5 Production Department the site location of which is given in Chapter I. Tyre 5 was selected for the following reasons.

a. Incoming steam supply was well metered and controlled, making for easy determination of consumption. Live steam was only used for moulding purposes with a negligable quantity being consumed by air-curtains. Space heating was for the most part provided by exhaust steam from the process, (this being unmetered).

b. Process water was restricted to closed circuit recirculation with little make-up, the main usage being the mill line and hydraulic circuit. Inlet and outlet temperatures, plus some flowrates, could be readily assessed.

c. Electrical consumptions were well monitored, individual metering existing on the mill-line.

d. A new line of Autoform presses had recently been installed with updated pipework lagging specifications, thus making provision for controlled experimentation.

e. Both Bagomatic and Autoform presses were present, giving provision for comparison.

f. E.G. Gould (88) had previously investigated energy performance and initiated action on a number of 40.5 inch Autoform presses in 'C' line. Using thermography, a direct comparison of efficiency ratings between two presses could be made, thus enhancing Gould's work.

g. Presses and moulds could be halted, in either the open or closed position, for analysis.

h. Tyre 5 building, services and equipment were well maintained relative to other departments in the factory.

Certain disadvantages, however, co-existed:

a. The condensate return was not readily measured making evaluation of heat out of Tyre 5 more difficult.

b. Curing cycles, and hence heat loss from presses, varied according to the type of tyre being moulded.

c. The expected variation in emissivity of surfaces was in evidence, particularly with the use of aluminium moulds.

In entirety, however, energy usage in Tyre 5 was more easily controllable which, together with the relatively well maintained plant, equipment and building, provided the most suitable venue for the experiment.

Equipment Used:

The ensuing thermograms were rephotographed from the original photographs produced by the AGA 680 Thermovision system. These are shown in Appendix B.

In addition, spot surface temperature measurements were taken using a thermocouple and meter. Ambient conditions were monitored with a mercury thermometer. The steam conditions of temperature and pressure were monitored at the respective points using standard equipment. Black and white photographs of the areas incorporating the actual thermograms were taken with a standard 35mm camera.

8.3.1 Experimental Procedure

The general procedure for the forming and recording of each thermogram described in Chapter VI was observed, the duration of the colour exposures taking between 4 and 12 seconds each. It was, therefore, necessary to ensure that the object being viewed was in a state of thermal equilibrium prior to exposure. The average time taken to achieve a thermal picture record,once the equipment had been positioned,was 4 minutes. This enables a constant check to be made on the reliability and content of each thermogram before pursuing the next case.

In certain instances it was possible to view the object in question using two or more sensitivity selections so as to build a more composite picture of heat loss. An example of this can be found on Plate 8D.

In all cases, thermograms were accompanied by photographs of the object being viewed. This was essential to their comprehension at a later stage.

In addition to the thermograms, spot and ambient conditions were noted using a traditional thermocouple. Steam conditions at the measured pressures were assumed to be dry saturated. Such measurements provided the necessary reference for comparison with thermograms. The thermogram reference temperature was specified and measured in each case. It was not possible to use a black body simulator,enforcing estimation of emissivity for each reference.

As far as possible, objects being viewed were screened from alien radiation sources, such as sunlight and adjacent hot radiators, so as to minimise the adverse effects of reflected radiation. Due record was made of the materials of the object(s) being viewed to assist in assessment of emissivity.

8.3.2 Interpretation of Results

The interpretation of each thermogram followed the procedures laid down in Chapter VI, Direct Temperature readings were not possible, due to the extensive object temperature ranges and materials being viewed. Due care and attention was given to the emissivity of the materials being studied. Final temperatures were, therefore, derived from the basic formula and calibration charts.

For the most part, the objects being viewed were dirty, sometimes covered in oil and oxidised. In the cases where emissivities could not be derived from tables, an average value of 0.9 was adopted. This value is in accordance with that estimated by AGA for the majority of industrial surfaces. (156).

The viewing distance in all cases was greater than 2m and less than 20m. There was, therefore, no need to consider attenuation effects. Similarly, the composition of the Tyre 5 atmosphere, although polluted with fumes from the moulding area, was not sufficient to effect the results.

8.4. General Description of Thermograms

Plates 8A and 8B

Location = Low pressure (LP) steam main, 'D' line subway.

A1 : 38.1 mm (1½ inch) fibreglass insulation covered with fabric for external protection and fastened to the 102mm (4 inch NB) steel 120 p.s.i. steam pipe with a galvanised-steel strap. The reference was the concrete wall. Points of note include the insulation joint; the effect of emissivity of the strap on recorded temperature : the higher insulation temperature the upper facing surface; and the red corner of the cardboard reflection shield above the pipe.

A2 : 25.4 mm (1 inch) magnesia insulation with an interface with the above mentioned fibreglass, without the fabric protection and fastened to the same section of pipe. The reference was the concrete wall. Additional points of note include the comparative higher surface temperature of the magnesia and the higher losses at the interface.

A3, A4, A5 : Lagging removed from a section of the 102mm (4 inch NB) pipe together with a cross section of the above mentioned fibreglass insulation. The Reference was the upper lagged surface. Points of note include the high temperature of the unlagged pipe, the temperature differential across the lagging section, and the nonuniformity of heat released from the pipe in A3.

Plate AC

Location: South wall above service trench.

B1 : Displaced fibreglass insulation on the exhaust, L.P. and H.P. steam pipes feeding the services subways, remaining insulation being covered with a fabric protection held to the pipework by dirty galvanised straps. The reference was the concrete wall. Points of note include apparent minimised emissivity effect of straps, these having the same temperature as the lagging; and the high heat release from the uninsulated pipework.

Plate 8D

Location: Roof space at east end of moulding area.

B2 : Displaced fibreglass and aluminium cladding on the LP and exhaust steam pipework (6" and 5" respectively). No reference. Points of note include non-uniformity of temperature distribution, the greater valves occurring nearer the insulation and flange.

B3 : As above but showing the lower temperatures and the loss from the exhaust main flange. The reference was the roof space. Points of note include the relatively high loss from the flange compared to the surrounding fibreglass/ fabric clad insulation on the pipe, and the apparent effect of emissivity on recorded temperature of aluminium cladding, the values appearing to be the same as those for the roof space.

Plate 8E and 8F (C1)

Location: Low Pressure (LP) steam main in 'D' line subway.

B4 : Unlagged flange on end of L.P. steam main clamped to wall with a metal bracket, and condensate collection with atmosphere valve from HP steam main. The reference was the concrete wall. Points of note include the variation of heat loss from the flange; the non-uniformity of the weld;

the high loss from the bracket, and the loss from the condensate pipework and valves.

C1 : Correctly functioning TD steam trap on the LP main. The reference was the concrete wall. Points of note include the apparent temperature differential between the steam and condensate sides of the valve and trap.

<u>Plate 8F</u> (C2)

Location: Roof space at east end of moulding area.

C2 : Safety valve arrangement for steam discharge. The reference was the roof space. Points of note include the inability to detect escaping steam; and the warm filament of the incandescent light.

<u>Plates 8G, 8H and 8I</u>

Location: Rear of C1 Autoform press.

A16 & A17 : Two correctly functioning TD steam traps. The reference was the ambient conditions behind the press. Points of note include the temperature differential across the trap.

A14 & A15 : Diaphragm valve. The reference was the ambient conditions and the rear of the press framework. Points of note include the uniform temperature across valve A15, showing its open position, the high heat loss from both valves, and the inability to detect the valve position when lagging is on the pipework.

Plate 8J

Location: Mill line for profile calender.

D1 & D2: Temperature distribution in rubber compound being milled on the central rolls. The references in each case were the framework of the machine. Points of note include the higher temperatures in the centre of the rubber, the increase in temperature with time (D2 to D3 $\simeq$ 1 minute time difference), and the increased conduction of heat to the mill framework with time, ∴ the outer rubber layer becoming hotter.

Plates 8K, 8L, 8M, 8N, 8O, and 8P

Location: 'C' line autoform presses.

E2 & E4: Left hand mould of C6 press in a closed and open position respectively, complete with thermal skirt and additional Sindanyo insulation between platten and base plate. The reference was the press chassis. Points of note include the high heat release from the gap in the skirt, the higher temperature between the moulds, the hot spot in the centre of the base plate interface, the hot pipework at the front of the press, the relative reduction of convected heat to the chassis when compared with E1 and E3, and the increased heat loss with the moulds open.

E1 & E3: Left hand mould of C7 press in a closed and open position complete with thermal skirt but having only a single layer of sindanyo between mould and baseplate. The reference was the press chassis. Additional points of note include a general increased conduction of heat below the baseplate, and a lower temperature between the moulds.

A1 & A4: Right hand mould of C7 press in a closed position and without thermal skirt or additional sindanyo, plus detail of the steam valve positions showing isolation of the left hand mould. The reference was the press chassis. Points of note include the large radiation loss from the unskirted mould and uninsulated pipework, the increased conductive losses through the base plate, the transfer of heat by radiation to the unused mould due to lack of skirting, and the ability to detect whether valves are open or shut.

A7 & A8: Right hand mould of C6 press in a closed position, with thermal skirt and double sindanyo insulation, plus details of the steam valve positions. The references were the skirt and the green cover. Points of note include the lower sensitivity and hence the lower temperature of C6 base plate compared with C7, less heat loss from the mould due to the skirt, and the suitability of thermography to test positions of valves.

Plate 8Q

Location: 'A' line bagomatic press.

F1 & F2: Upper mould of open bagomatic press. There was no reference. Points to note include the extensive radiation of heat from open moulds, the apparent temperature differential across the mould, and the relatively low sensitivity setting brought about by the low emissivity of the aluminium mould.

8.5. Records and Results

Quantitative interpretation of a number of thermograms from plates 8A to 8Q were made. The resultant temperatures of the relevant isotherms are given in Appendix B . In theory calculation should have been based on equation - 1 (Section 6.5). This, however, involves a larger number of parameters and consequential measurements. For the most part, the reference temperature was taken to be the unfocused background temperature (Tr = Ta), hence equation - 4 was used for simplification:

$$Io = \frac{ior}{\epsilon o} + Ir.$$

Use of this equation made the basic assumption that $\epsilon r \simeq 1$. In practice, $0.9 < \epsilon r < 1$, which leads to inaccurate assessment of Ir and consequent error in determining temperatures of other isotherms.

Ambient external air temperatures measured at Elmdon Airport, Birmingham were:

6°C	(Rain)	-	Friday 18th February, 1977
7°C	(Showers)	-	Monday 21st February, 1977
14°C	(Sunny)	-	Monday 4th July, 1977

Average internal building temperatures Tyre 5 were:

25°C	-	Friday 18th and Monday 21st February 1977
33°C	-	Monday 4th July 1977

8.5.1 Insulation (Plates 8A and 8B)

a. Qualitative Observations

- Heat loss from the unlagged pipework was extensive (A5)
- There was a large but clear temperature differential across the fibreglass lagging (38.1 mm) (A5).
- The external temperature of the magnesia lagging (25.4 mm) was higher than that for (38.1 mm) fibreglass, thus having greater heat loss. (A2)

Table 8.5.2

Calculation of Heat Loss from Surface Temperatures.

in Btu./ft^2.hr.

$$Qr = 0.174\,\epsilon \left(\left(\frac{Ts}{100}\right)^4 - \left(\frac{Ta}{100}\right)^4 \right)$$

$$Qc = 0.296 \quad (ts - ta)^{5/4} \sqrt{\frac{v+68.9}{68.9}}$$

Based on D. Barnett calculations used in energy conservation (158) - see section 6.5.

Surface temperatures = Ts and ts in ^oR & ^oF respectively

Ambient temperatures = Ta and ta in ^oR & ^oF respectively

Wind velocity = v = o for internal thermograms.

Total heat loss Qe = Qr + Qc

- Heat loss was greatest at the lagging joints, with temperatures also being higher on the upper-most surfaces (A1 and A2).

b. Quantitative evaluations

- The calculated temperature of the bare pipe (102 mm dia) (A5) was 190 to 194°C, the emissivity effect (0.95) being uncertain. The estimated heat loss was put at 8854 MJ/m^2/hr., based on the following formulae in Table 8.5.2 and an ambient temperature of 25°C. The prominent form of heat transfer at these temperatures was radiation. The pipe surface temperature compared with that of +176°C for saturated steam at 8.3 bar pressure. However the steam was expected to have some superheat.
- In contrast the average external temperatures and heat losses are given in Table 8.5.3 (A1, A2 and A5).

Table 8.5.3.

Average External Temperatures and Heat Losses for the 8.3 bar Steam Main Tyre 5.

	Bare Pipe (102 mm)	Fibreglass (38.1 mm)	Magnesia (25.4mm)
Surface temperature average - °C			
Minimum	190	25	39
Maximum	194	26	41
difference - % min.	2.1	4.0	5.1
Heat loss - MJ/m^2/hr.			
Minimum	8455	Small	379
Maximum	8854	89	444
difference - % min.			

Assuming ambient conditions of 25°C.

- Losses were markedly reduced with first the magnesia lagging and still further with the fibreglass. It should be noted,that at lower temperatures,the effective heat loss calculated varied significantly with disparity of temperature measured and hence the emissivity effect. Calculation of surface temperature was therefore critical.
- The temperature differential across the fibreglass insulation was (194-26 = 168°C)(A5). With such large differentials, and indeed the interval of comparison with the reference temperature, accuracy could not be certain.
- Variations in surface temperature of lagging were: 25 to 44°C for fibreglass and 39 + 44°C magnesia; the effective temperature of each joint being 50°C and 47°C respectively (A1 and A2). The higher upper surface temperature was expected,since hot air trapped in the lagging will tend to move upwards. In addition, there was the effect of reflected and absorbed radiation emitted from the 13.8 bar (200 psig) steam main positioned above, raising this part of the lagging to a higher temperature.

c. <u>Comment</u>

- The accuracy of temperature measurement and hence heat loss was questionable,particularly at low temperatures. Interpretation of marker positions, estimation of emissivities, and computation of isotherms could have severely effected the final results. Variation of estimates for heat loss was shown here to exceed 17%.
- Low surface emissivity was clearly detected in A1 with the apparent low temperature of the metal band, which in

reality was at the same level as that for the fibreglass. When attempting to account for low emissivity, it was not possible to attain useful results based on the equation - 4 interpretation of thermograms. It was necessary to utilise equation - 1. This inferred increased computation complexity and additional measurement.

- The conclusion was that thermography could not provide accurate quantitative analysis of heat loss from low emissivity surfaces using the simplified techniques.
- There was no question that thermography could be usefully deployed in estimating heat loss from surfaces with higher emissivities, provided the object temperature was not far removed from the reference and that computation using the calibration curves was not confined to the lower echelons of the exponential. Here a small variance in isotherm units could represent a large variance in the temperature of the object.
- As a qualitative tool for determining the effects of certain actions on heat loss, the technique has clearly demonstrated its effectiveness from this example of insulation analysis. It was essential to realise, however, that the effects of emissivity could be misleading if the object being studied was not known to the observer.
- Finally, the effectiveness of insulation, of the correct thickness and adequately installed is beyond question.

8.5.2 Housekeeping (Plates 8A, 8C, 8D, 8E, 8H, 8L, 8M, 8O, 8Q)

a. Qualitative observations

- (A1 and A2) Heat loss through split lagging brought about by poor installation, not visually detectable, was significant.

- Heat loss from removed or damaged lagging was high (B1) compared with the well insulated sections.
- It was necessary to lag flanges (B3 and B4).
- Heat loss from pipe brackets (B4) and uninsulated valve assemblies (8H) was significant.
- Moulds without thermal skirts radiated large quantities of heat (8M).
- Heat loss from open presses were large (F1).
- Detection of steam leaks (8F) was not possible at normal settings and with standard filters.

b. Quantitative evaluations

- The additional heat loss per m^2, brought about through incorrect installation of pipe lagging (A1), was proportional to the temperature variation between the split insulation (White = 50°C) and the remaining surfaces (Green = 25°C). These losses, however, tended to be minimal, due to the small effective surface area.
- The consequential heat loss from the damaged lagging (B1) on both the 152mm (6 inch) steam mains was put at 12872 $MJ/m^2/hr$. The loss from the 127mm (5 inch) exhaust steam main was less at 4163 $MJ/m^2/hr$. Calculation of actual temperatures (Figure 8.5.4) showed differences between the HP and LP steam mains. This, however, was not detected by the thermogram, which gave both pipes to be 235 to 239°C. It was suspected that these temperatures were slightly high, due to the reference temperature being far removed from such levels. Degree of steam superheat could not be estimated, however, which if included would have minimised this discrepancy. The

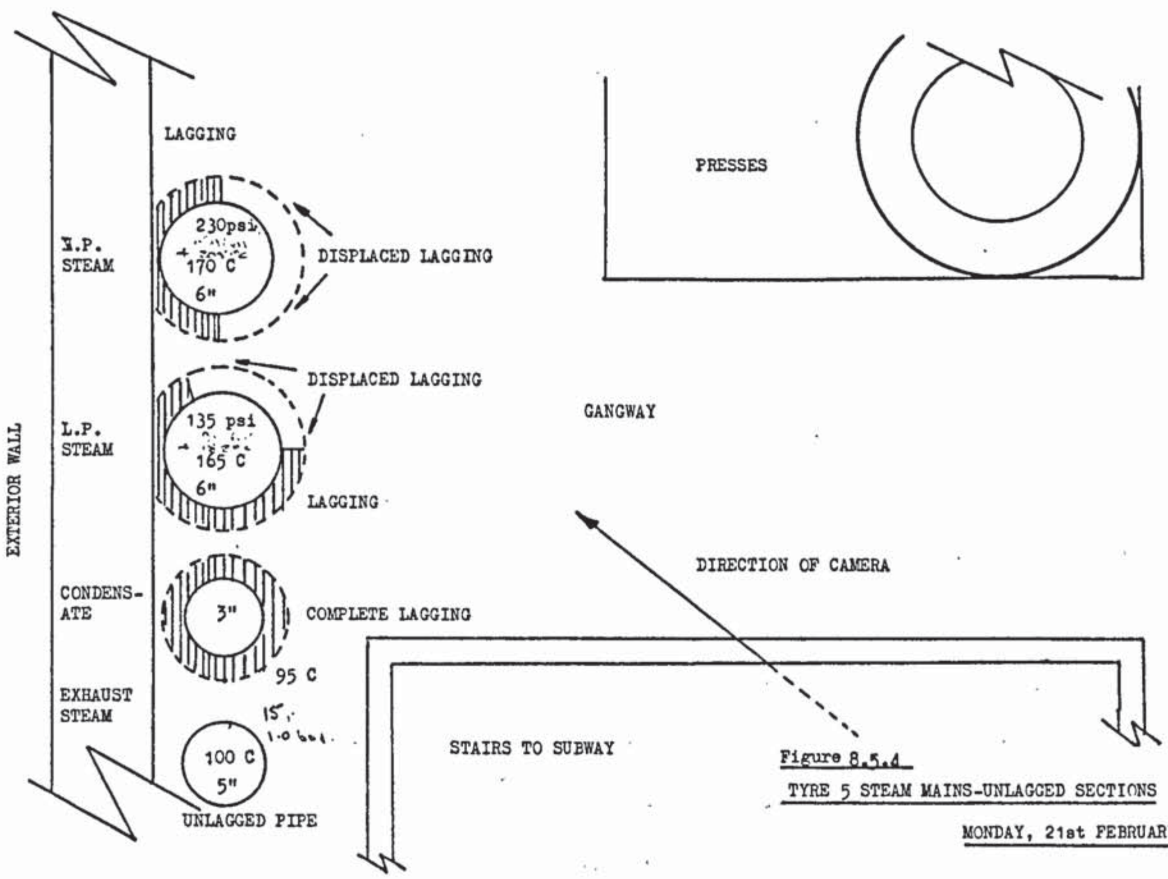


Figure 8.5.4

TYRE 5 STEAM MAINS-UNLAGGED SECTIONS

MONDAY, 21st FEBRUARY, 1977.

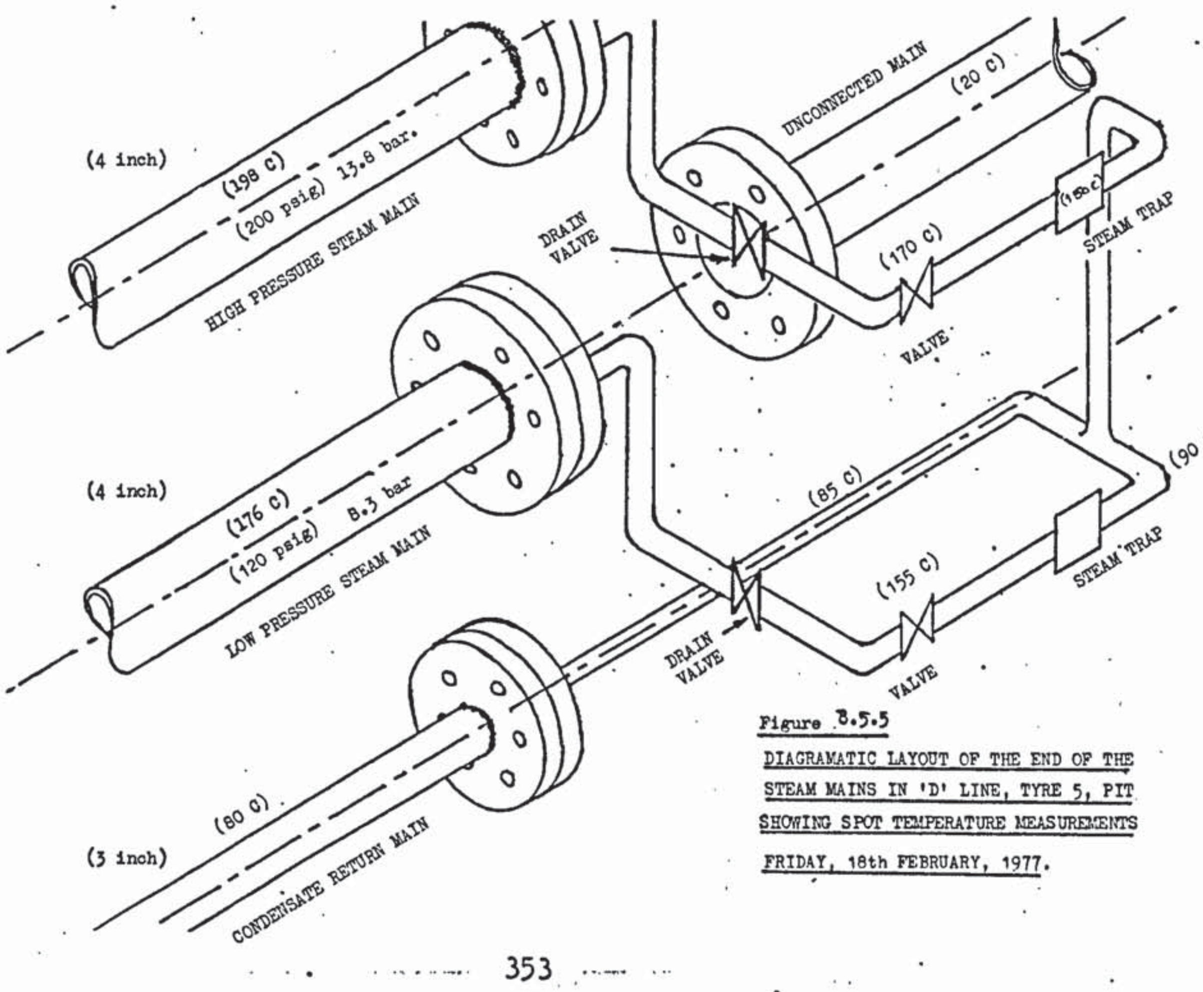


Figure 8.5.5

DIAGRAMATIC LAYOUT OF THE END OF THE STEAM MAINS IN 'D' LINE, TYRE 5, PIT SHOWING SPOT TEMPERATURE MEASUREMENTS

FRIDAY, 18th FEBRUARY, 1977.

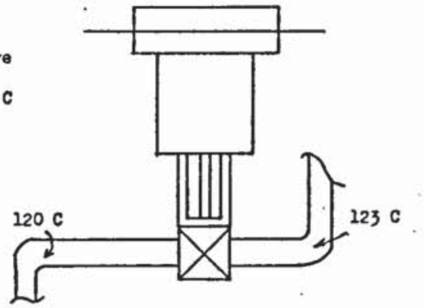
difference between 'black-body' and 'real' temperature measurement was small.

- The temperature of the exhaust steam uninsulated pipe was calculated at 128°C. With exhaust steam at 2 bar absolute, dry saturated, the temperature of the pipe was 120°C. These compared favourably with an accuracy of 7%, deviation most likely being due to a low reference level selection.
- The bright galvanised steel bands clamping the white lagging to the 76mm (3 inch) condensate main clearly showed reflection of heat from the LP steam main, giving an inaccurate surface temperature for the metal of 190°C based on computation by equation - 4. This compared with its black body temperature of 127°C and its real temperature of 25 - 30°C.
- The heat loss from flanges was found to be 4355 $MJ/m^2/hr$ for (B3) and + 7140 $MJ/m^2/hr$ for (B4). These related to average surface temperatures of 131 and +173°C respectively. Actual measurement (Figure 8.5.5) of (B4) by thermocouple was 176°C, a favourable comparison. Since in both cases the reference temperature included the lagging, the heat savings through insulation can be said to be large at over 4000 and 7000 $MJ/m^2/hr$ respectively.
- The heat dissipation up a valve housing was substantial (8H) (8I). The temperature of the upper valve sections were +90°C, with 160°C close to the proximity of the pipe. These, however, did not compare with the measured temperatures given in Figure 8.5.6. Reasons for this included the large differential between object and reference temperatures, the unreliability of the

Figure 8.5.6 Valves and Traps on Steam Lines to 'C1' Autoform Press - Temperature Recordings

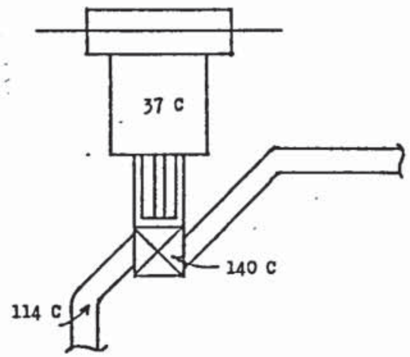
Ref. Plate H
Diaphram Valve

Ambient = 33 C



Ref. Plate I
Diaphram Valve

Ambient = 33 C



Ref. Plate G
Steam Traps

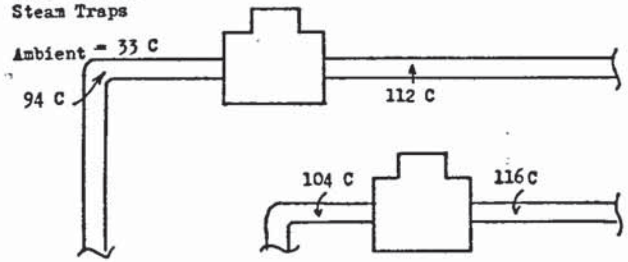
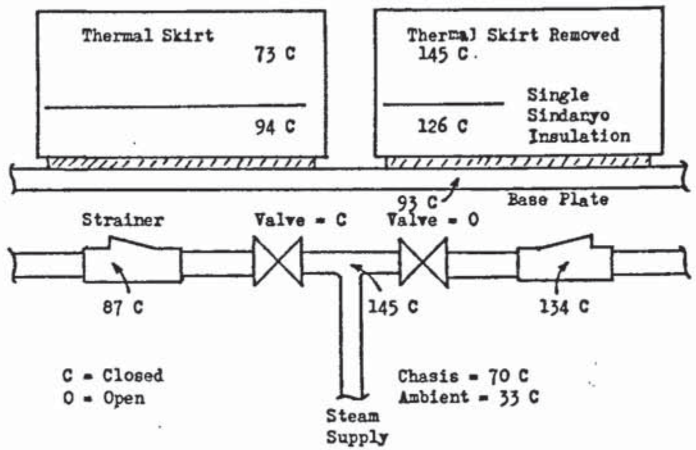
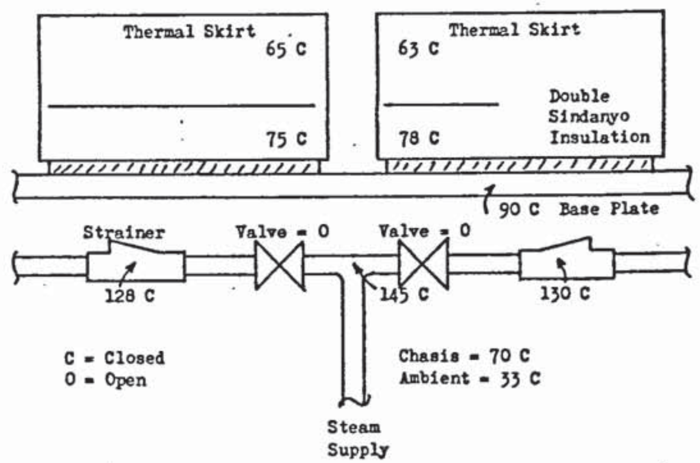


Figure 8.5.7 'C7' Autoform Press - Temperature Recordingz



'C6' Autoform Press - Temperature Recordings



reference temperature, and thermocouple measurements. The findings, however, indicated the need to lag valves.

- The heat losses from open moulds (8L) (8Q) were found to be large, surface temperatures ranging up to +192°C for autoform and bagomatic presses. The temperature distribution as shown in 8Q was difficult to assess, due to variation of and existence of low emissivity for the aluminium surface. Corrected temperatures of 216°C max. were deemed unlikely.
- Comparison between plates 11M and 11P indicated heat losses of 6931 $MJ/m^2/hr$ for the 'un-skirted' mould, and only 1450 $MJ/m^2/hr$ for that with the thermal skirt in place. Surface temperatures for each were 170°C and 70°C respectively. Thermogram, A3, clearly showed the absorption of heat by an isolated left-hand mould. Figure 8.5.7 gives the actual thermocouple measurements taken. Discrepancy was once again apparent at the higher temperature echelons, probable reasons being those previously given.

c. Comment

- The accuracy of temperature and heat loss determination was in question. Discrepancy and/or inaccuracy appeared to be larger at higher temperatures. Probable reasons included.

  a. large differencies between object and reference temperatures.

  b. inaccurate reference source.

  c. faulty conventional thermocouple readings.

  It was unlikely that computation using the calibration curves would have produced such anomolies. In consequence to further investigation, the third reason appeared the most likely. Thermogram isotherms were reading approximately 17% higher than thermocouple measurements at temperature of +140°C.

- As in 8.5.1. low emissivities posed further difficulty with computation based on equation - 4. For normal emissivities >0.9, there was little variation between 'black-body' and 'real' temperatures, even at the higher levels.
- The use of thermography in detecting unlagged hot surfaces, poor installation, brackets and valves, was beyond question. Similarly, quantities for temperature variance and heat loss could be readily attached to coloured isotherms with assurance of small error. The most accurate estimates of loss, however, showed during comparison of isotherms on the same thermogram; i.e., comparative wastage could be assessed.
- A major contributor to poor housekeeping is steam leaks. The normal thermogram, however, using standard settings, was unable to detect such loss. Steam leaks on the other hand tend to be visible and could be photographed anyway. As an instrument in identifying good house keeping, therefore, thermography was judged a powerful tool.

8.5.3 <u>Valve and Steam Trap Condition</u> (Plates 8F, 8G, 8H, 8I, 8N, 8P)

a. Qualitative Observations

- (C1) The valve could be seen to be open (the yellow isotherm being a product of lower emissivity for brass compared with the steel pipe), but the clear drop in temperature across the steam trap indicated its functioning correctly. Similar examples were found in (A17)

- The valve in A15 was clearly misleading, since the apparent drop in temperature as seen by the camera was due to the presence of lagging down-stream. It was impossible to tell whether this valve was open, closed or passing.
- (A14) showed a valve with cladding on both up and downstream pipework. No variation in temperature across the valve could be detected through the insulation thus making identification of the condition impossible.
- Without lagging (A4), valves on the front of a press could be seen to be open (right hand cock) or shut (left hand cock). A contrast was made with A8 where both valves were open.

b. Quantitative Assessment

- The temperature variance measurement across a valve or trap was deemed essential to determine condition. The results obtained are given in Table 8.5.8. Temperatures were compared with the thermocouple measurements given in Figures 8.5.5 to 8.5.7.

Table 8.5.8 Temperature Differential Measurements Across Valves and Traps

Thermogram	C1	A17	A15	A14	A4	A8
Upstream temperatures - °C						
Thermogram -	207	172	160	170	169	180
Thermocouple -	170	112	123	140	145	145
Downstream temperatures - °C						
Thermogram -	123	128	95	95	71	117
Thermocouple -	90	94	120	114	87	130

- Differentials, although varying in value from thermogram to thermocouple readings for reasons given in section 8.5.2, were consistent for C1 but not for A17. From the thermocouple measurements these traps were passing, yet according to the thermograms they were not. The discrepancy was believed to be due to variation in emissivity, thus casting doubt on the use of this method of loss identification.
- According to the thermocouple readings, valve (A15) was either open or passing. From the thermogram, however, as with (A14), the presence of insulation inhibited any direct identification.
- For both (A4) and (A8), however, it was clearly proved that despite differences between thermogram and thermocouple readings, temperature differentials were sufficient to judge the state of the valves.

c. Comment

- Once again, it was believed that inaccuracy or discrepancy between the thermogram and thermocouple measurements could be attributed to variance in the latter, particularly at higher temperatures.
- The condition of a valve or trap relies on the assumption that a temperature drop will occur if the valve is shut or the trap is only discharging condensate. Should the valve be open or both valve and trap be passing, the temperature on both sides will be identical. The detection of this differential is, therefore, critical; effects of varying emissivity on up to down stream measurements could produce anomalies. If a valve or trap failed to open at all, the temperature drop must be assumed to be much larger.

- Assuming constant emissivities both up and down stream, and bare pipework, thermography could adequately detect the state of valves and traps. In contrast to ultrasonic methods, the technique could advantageously be employed remotely. Presence of lagging together with emissivity variation, however, presented difficulties not experienced when using the ultrasonics method. It was therefore doubtful whether thermography could replace the use of ultrasonic detection of passing valves and traps. This statement was also endorsed by the fact that ultrasonic detectors were of the order of 100 times cheaper than thermographic equipment. In addition, it was necessary to realise the state of the valve being viewed, since it appeared impossible to differentiate between an open or passing valve.
- Valves of the type shown in (A4) could be visually identified as being open or closed albeit that should these be passing steam, lack of temperature variance would have to be noticed.
- In principle, temperature differentials across valves and traps could become a useful way of monitoring effective performance and minimising loss. The obvious direction would be to research the possibility of automatic condition monitoring using thermocouples, with analog inputs to some form of microprocessor. Foreseeable difficulties would include judgement of the spacing of thermocouples at sufficient distance from the valve or trap to avoid conduction effects through the metal, the degree of sensitivity, and the non-isotropic behaviour of the steam.

8.5.4 Production Control - Milled Compound (Plate 8J)

a. Qualitative observations

- Comparison of D2 to D1 showed the increase in rubber temperature during a milling operation over a one minute time span.
- As expected, temperatures increased from the centre of the rolls towards the ends.
- The temperature of the end of the shiny mill roll increased as expected.
- There was only a slight heating up of the framework.

b. Quantitative assessment

- The temperature of the rubber increased from 95°C to 106°C in the centre and 80°C to 95°C at the periphery over the 1 minute duration.
- The apparent temperature of the mill roll increased from 80°C to 90°C. Exact temperatures would have needed emissivity correction.
- Removal of heat from the rolls was 380 MJ/hr by 2300 litres/hr of cold water (20°C inlet, 24°C outlet) delivered through a 32mm (1¼ inch) pipe.

c. Comment

- Rubber compound is milled to attain the required consistency and composition by raising its temperature to a critical level through means of internal molecular distortion induced by electrically driven mastication. Should the temperature become too high, the vulcanising constituents will commence pre-curing of the rubber which may lead to scraped compound. Likewise 'under-processing' will not yield the required physical properties. From process point of view, therefore, notification of temperature condition to within the specified limits is essential. The thermographic measurements have proved their suitability to this aim.

- Energy savings could accrue by limiting operation of mills to the minimum temperature limit, thus saving expensive power. Whilst perhaps impractical as a permanent installation to every mill line, periodic checks using thermography could be made on milling operations to attain this result. Care would need to be taken to ensure an accurate reference temperature.
- Unlike other materials, rubber has a suitably high emissivity, hence the results did and would not suffer from anomalies and/or consequential laborious correction.

8.5.5 Heat Distribution on Moulding Surfaces (Plate 8Q)

a. Qualitative observations

- There were apparent variations across the upper mould of the A1 bagomatic press.
- There was no clear progression of temperature gradient in any one direction.
- The centre of the mould appeared to be cooler.
- The emissivity effects for aluminium (the tread section of the mould) gave apparent lower temperatures than the steel components.
- The highest temperatures were shown on the central and periphery sections of the steel platten itself, to which the mould was attached.

b. Quantitative assessment

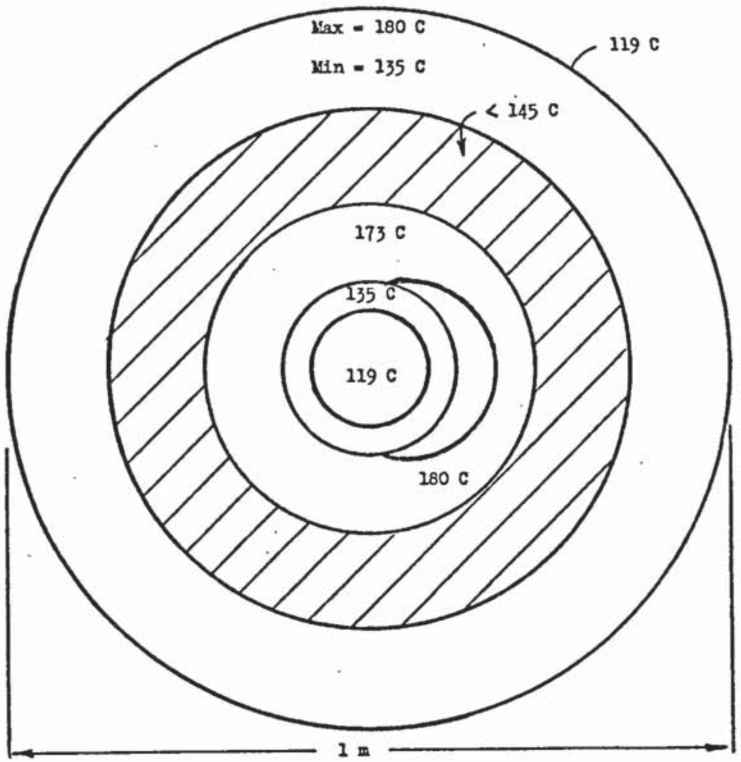
- Figure 8.5.9 gives the average temperature distributions calculated from the thermogram. Variations on the platten periphery were believed to be due to emissivity, parts being dirtier than others. It was thought unlikely that a physical differential of 45°C could have existed across any section.

- The platten does not cover the entire upper chassis plate but has a hollow centre. This accounted for the cold central area 119°C to 135°C of the thermogram, and the contrasting yellow and white isotherms to the right of centre (180°C), which was a part of the platten.
- The large red area represented the steel sidewall section of the mould at a consistent temperature of 173°C.
- The greatest variations, together with lower apparent temperatures, were found on the aluminium tread section. Here emissivity severely affected recorded temperatures. The reliability of readings could not be guaranteed.

c. <u>Comment</u>

- The use of thermography in technical design and experimentation was obvious. From such thermograms as these, uniform temperature distribution could be attained a factor important to consistent moulding.
- The tyre mould, however, is one example of varying material composition and consequent emissivity changes. Once again, materials having lower emissivities presented a problem producing unreliable measurement. Similarly, it was of interest to note the effect on temperature of emissivity of the dirtier sections of the platten.
- It was essential for the observer to realise the composition of the mould. Temperature distributions, should they be of the order recorded, could not be tolerated. Had decision to carry out modifications been based on the results of the thermogram and without understanding of emissivity variance, time, manpower and

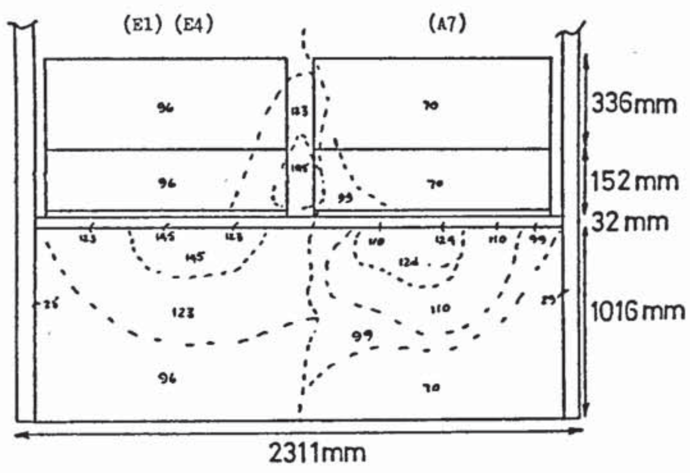
Figure 8.5.9 Temperature Profile Across an Open Press Mould (F1) (F2)



Aluminium Mould

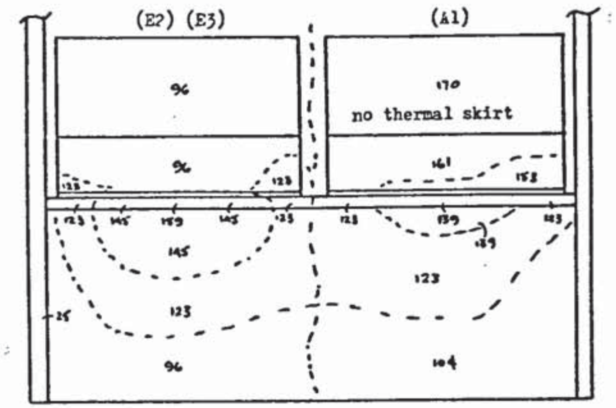
Estimated heat loss - Max. = 6000 MJ/hr.
Min. = 5400 MJ/hr.

Figure 8.5.10 Dimensions and Temperatures for C6 and C7 Autoform Presses



a) C6 40.5/300 Autoform Press with Double Sindanyo Insulation

b) C7 40.5/300 Autoform Press with Single Sindanyo Insulation



Dimensions as above

money would have been wasted.

- Finally, accurate temperature measurements were restricted by computation difficulties, with the calibration curves at low isotherm levels, and the absence of an accurate reference temperature.

8.5.6 <u>Heat Loss from Autoform Presses</u> (Plates 8K, 8L, 8M, 8O)

The ensuing investigation on autoform presses, with its comments and results, were initiated as a means to verifying the work carried out by E G Gould (88). This work has already been described in Chapter <u>VI</u>. In brief comparison was made between two presses, C6 having a double layer of insulation between platten and base plate. The objective was to identify the change in heat dissipation to the press chassis and where possible quantify the difference.

a. <u>Qualitative observations</u>

- There was increased conduction of heat through the Sindanyo insulation to the base plate and lower chassis of press C7 (E1) compared with C6 (E2); both were left hand moulds.
- There was an apparent increase in temperature between the mould-skirts for C6 (E2). This may have been due to an emissivity effect.
- The temperatures of the pipework in front of both presses were off the thermographic scale. These required lagging. (E1) (E2) (E3) (E4).
- There was no apparent difference in heat dissipation to the lower chassis of presses C6 or C7 when they were in either the open (E3) (E4) or closed (E1) (E2) positions; the only difference being the large loss from the mould itself.

- There were obvious increases in radiant heat from the right hand mould of C7 (A1), due to the removal of the skirt.
- The temperatures at the base plate and lower chassis of press C7 (A1) were higher than for C6 (A7).
- The horizontal chassis members were relatively cool.

b. Quantitative assessment

- The temperatures computed are given in Figure 8.5.10. It was interesting to note certain discrepancies between temperatures recorded on separate days for the right and left hand moulds of both presses. Excluding the absence of the thermal skirt, which showed great heat loss, temperatures were high for the left hand moulds. This was most likely due to the variation in ambient and steady state conditions for the two days, Friday, 18th February and Monday 4th July 1977, on which the left and right thermograms were respectively recorded. Secondly, the reference temperatures for (A1) and (A7) were accurately monitored.
- In addition, there appeared a discrepancy between the thermocouple (Figure 8.5.7) and thermogram temperatures, particularly at higher values. Variance was believed to be a product of inadequate thermocouple contact with the object, giving over 45% difference in base plate temperature.
- Additional insulation on C6 reduced the base plate and adjacent lower chassis temperatures by 9 to 11%. The downward spread of higher temperature isotherms was greater for press C7. Based on thermograms (A1) and (A7), the heat loss differential at the base plates of C6 and C7 presses was 1084 $MJ/m^2/hr$. The difference for the

low chassis was 674 MJ/ ^{2}/hr. Based on these measurements, reductions in heat loss of 22% and 18% were calculated. According to E G Goulds measurements (88), only a 3.3% reduction in heat loss could be expected. Goulds loss reduction, however, was based on total platten steam measurement,which included losses from the back and sides of the press. The thermographic results were based only on the frontal area of each press. Together with the relatively complex distribution of temperature, it was impractical to assess total heat reduction beyond concluding that the temperature and heat conduction to the base plate from the platten had been reduced with the additional thickness of insulation.

- In conclusion, despite the apparent discrepancies between the thermograms and other measurements, the study upheld E G Goulds (88) reported findings and that thermal skirts should be employed on all presses.

c. Comment

- There was once again reason to believe that the thermocouple readings were inaccurate at higher temperatures. Quantitative validation of each thermogram was therefore in doubt and disappointing. However, it was possible to establish that an improvement had been achieved using thermographic techniques.
- The importance of accurate reference temperatures could not be overstressed. This alone was the most likely cause of variance between for example (E1) and (A7).
- Apart from the obvious that there was still much to be done to reduce heat loss from presses through improved insulation, exercised caution questioned whether loss through passing valves and traps might not have been of

greater waste.

8.6. Concluding Discussion

With the initial objective to establish the practical feasibility of the use of thermographic techniques for the qualitative assessment of thermal efficiency and/or heat loss, this exercise proved beyond doubt that, as a means to identification of inefficiency, the standard thermogram holds great potential. An engineer or technologist, conversant with interpretation of thermograms can readily inspect plant and equipment from a remote position and determine the effective performance. This is of course with the provisos that a full appreciation is held of the objects being viewed, and that the engineer is familiar with the thermographic equipment and its adjustment.

Quantitative analysis of first temperature and later heat loss is less certain. The list of problems and difficulties is lengthy. The initially apparent simple technique for identifying inefficiency becomes conclusively more complex. Concurrent with thermographic analysis, additional measurement is often needed.

8.6.1 Thermographic Equipment

The AGA Thermovision 680 (156) is primarily a semi-portable piece of equipment particularly suited for laboratory study and 'fixed-position' scanning of industrial sites, plant and equipment. Used in the context of an energy conservation monitoring role, the camera and monitor are cumbersome, making quick investigation of specific plant less practical. This equipment requires a mains power supply and a stable base for the camera-tripod. These requirements are not always available.

To be fair to AGA and others manufacturers, more portable systems are available.

The AGA Thermovision 750 and 780, lightweight camera systems are an example. These provide the usual 'live' presentation of temperature distribution on fixed or moving objects. However, it suffers from reduced operation accuracy and the absence of coloured isotherm facility in its basic state. The 680, used in these experiments, is at least more stable when producing permanent records of isotherms.

No two thermograms need produce similar isothermal patterns. The isotherm units produced depend on adjustment of the black-picture level. Should alteration to this adjustment result at any stage, a different picture could result. Similarly, adjustment to the isotherm width or position will alter the final picture. These are serious drawbacks when the objective might be to study and compare the contents of a number of thermograms by simple observation.

Quantitatively, this problem should not emerge, since each thermogram taken bases the recorded isotherms on the same reference temperature, each being assessed individually.

8.6.2 Operation, Observation and Interpretation

A primary requisit is to produce some form of permanent record of each thermogram. This is best achieved using a standard Polaroid camera giving instant photographs, which may be validated before passing to the next object of study. It is important for subsequent analysis to obtain a standard photograph of the area of study. This helps to clarify the thermograms at a later stage.

It is impossible to achieve accurate quantitative results without record of a suitable reference temperature. In certain instances, the sky, trees and walls of rooms can be used, but for exact measurement,the precise value must be known. Failure to observe this results in error. The reference source need not be a 'black-body' radiator, but for ease of calculation,a simulator of known dimensions and properties can greatly reduce the problems at a later date.

A thermogram used purely for comparative qualitative analysis, i.e., identification of hot spots, needs no such reference. This is indicative of the relative simplicity of thermographic techniques in identifying heat loss or inefficiency, but demonstrates the ever increasing complexity as quantitative requirements are introduced.

In addition to reference temperatures, measurements of spot temperatures, steam pressures within pipes, flow rates, and other properties may also be necessary to establish total energy distribution and loss. Thermography alone cannot apparently provide a total quantitative picture of energy usage. Associated with this is the need to record surface area accurately. Most loss measurements given in this chapter have been related to unit area. Complexity of the shapes of plant and equipment makes complete analysis difficult. Plain photographs cannot tell the observer the exact profile of the object being viewed. Should the objective be to establish comparative temperature measurements, there is no difficulty. Problems only arise when calculating heat loss.

By far the most adverse influence on accurate measurement is the emissivity of the radiating surface. Within normal industrial environments, emissivity cannot be accurately known without specific measurement. This defeats the main objective:- rapid and simple identification of its misuse. Most surfaces are dirty, covered in oil and consequently have high emissivities >0.9. The results obtained in this exercise have shown that correction for emissivities >0.9 produce, little change in temperature from those for the 'black body' assumption. For general scanning purposes, therefore, correction need not be made.

Problems of course arise with materials of low emissivity, where temperatures of isotherms appear colder than they actually are. Aluminium is one such common material. Low emissivity affects qualitative analysis as well. A knowledge of the objects being viewed is a primary requisite.

Surfaces with low emissivity also suffer from problems of reflected radiation emitted from other sources. Calculations of temperature must, therefore, include correction. In this exercise equation -4 was used, which was inadequate for low emissivity correction. Equation -1 accounts for such eventuality but requires a larger number of addition measurements and increased complexity in calculation. In conclusion, thermographic techniques cannot be easily used for analysis of heat loss from low emissivity surfaces.

For studies carried out at long distances or in adverse conditions, allowance should be made for attenuation etc. Ideally, clear atmospheric conditions are required, since accuracy may be affected by reflected radiation from steam leaks and other hot gas sources. In general, steam leaks cannot be readily detected at normal equipment settings and with standard filters.

In calculating temperatures from thermograms, a number of critical criteria other than those mentioned came into play:

a. The values of Tr and To should be as close as possible. Large differences tend to increase error.

b. Extrapolations based on the lower sections of the calibration curves are prone to error. A small variation in isotherm units will produce large variance in temperature.

c. Inaccuracy in reference temperature can bring about large errors particularly at higher temperatures.

All in all, quantitative analysis using thermography often presents severe problems. Suddenly from the simplicity of qualitative analysis, complexity is apparent as quantities are measured. AGA, however, have appreciated the problems and have introduced a standard programmable calculation to replace use of the calibration charts and equations. Similarly on the later camera models, manual correction can be made for low emissivity surfaces on the camera itself.

8.6.3 Concluding Comment

Although successful as a qualitative assessment technique, outside the confines of controlled laboratory conditions thermography has proved disappointing as quantitative measurement of temperature and heat loss. Absolute identification appears difficult in the industrial environment for the reasons previously stated in this section, the major problems being those of material emissivity variation, accuracy of reference temperatures, and computation complexity. However, in conclusion the following advantages can suitably be listed (164).

a. Achievement of <u>qualitative analysis</u> of heat loss and temperature differentials (i.e., identifying hot spots) is simple and quick to achieve by methods using remote sensing,which do not interfere with production activities.

b. Malfunction of service facility and equipment (i.e. passing steam valves and traps) can with due care be detected, thus providing a useful aid to maintenance.

c. Qualitative, and to some extent quantitative, comparisons of plant efficiencies, including before and after studies of conservation actions, are relatively simple to obtain.

d. Qualitative and quantitative evaluations of the effectiveness of insulation can be positively verified. This could lead to a new basis for reappraisal of economic lagging thicknesses.

e. Although not discussed at length, detection of flaws or non-homogenuity in materials (i.e., welded pipework (B4) and steam distribution mains (B2)) can be achieved without the use of X-Rays or X-radiation.

f. Production control parameters (ie milling temperatures and cycle times) and scrap generation (ie uniform calendering of rubber to fabric) can be simply implemented by thermographic monitoring. This is a substantial energy saver.

g. Uniformity of heat transfer (ie tyre moulds or rubber costing) and heat patterns within tyre treads can be evaluated in the technical R & D function.

Within confines of stage 1 - Thermography, there was as yet no proof that exterior surveys would have achieved the same success as a qualitative identification procedure, and even less certainty that quantitative measurements of building temperatures or heat losses could be obtained. The objective for the second phase experimentation was to examine such hypotheses with the view to establishing heat balances.

CHAPTER IX

THERMOGRAPHY EXPERIMENTS - STAGE 'THERMOGRAPHY II'

9.1 Chapter Preview

Having completed a general assessment of 'close-range' thermographic studies of specific plant and equipment, the second stage was to extend the investigation beyond the interior environments, thus examining the distribution of heat loss from building through global site studies. Was it possible to establish a meaningful assessment of overall energy usage using thermographic techniques? With major difficulties facing evaluation of energy balances from existing measurement methods, simple, quick and effective studies by the infrared camera could produce a major breakthrough within diffuse industrial operations.

This chapter reviews the experimental findings of an exercise aimed at these objectives. Studies were made and reported of qualitative and quantitative analysis of heat loss from an individual building, a steam distribution system, and the total site. The chapter is concluded with discussion on overall feasibility.

9.2 Objectives

Early experimentation involving thermographic studies (Chapter VIII) investigated the feasibility of detection of unwanted heat loss and misuse of energy from specified plant and equipment located in Tyre 5. The basic objective was to demonstrate that such a method of identification could determine heat loss in both a qualitative and quantitative manner. Although quantitative measurement was for the most part inconclusive, it was necessary to proceed with further studies on a more global scale; the prime objective being to establish quick identification and measurement of loss. A summary of the specified aims are as follows: (348) (349).

a. To make a global study of a department in its entirety, so as to establish a possible energy balance of inputs and outputs from that building.

b. To investigate the rate of heat loss from a steam distribution system using thermographic measurement.

c. To study heat loss from the entire factory site by obtaining from a remote position a series of thermographs of the factory roof tops. The ultimate aim was to establish an overall energy balance.

Previous comment already discussed in this thesis has laid down the difficulties involved in establishing patterns of energy use in diffuse industrial operations. Success of a global, remote sensing and effective identification procedure must define the basic goal for this study. Even qualitative assessment would be sufficient in itself to aid the evaluation process. Should thermography be an effective method, a major breakthrough in energy conservation thinking would result.

9.3 Experimental Specification

9.3.1 Experiments Selected

a. Tyre 5 was chosen for the departmental study since it constituted a single building, independent of surrounding factory configurations, with well metered incoming services such as steam, water, electricity and compressed air, a closed circuit cooling water system, and a relatively efficient operation. Disadvantages included:- unmetered condensate retain, with flash steam being discharged to the main factory exhaust main, thus creating an unmeasured heat output, cluttered areas surrounding the building periphery, variation in building materials, (asbestos roofing, brick and glass) thus creating problems of emissivity and transmissivity.

b. Study of the 350 psi West road steam main was taken as the most suitable distribution system since this had only recently been installed, had been well insulated with fibreglass within an aluminium cladding, and along most of the pipework, flows could be suitably assessed.

c. Investigation of total heat dissipation from the factory was carried out using remote sensing of building surface temperatures from high buildings in the vicinity. The Warstone Tower block and Dunlop Commercial Offices provide suitable panoramic views (Figure 9.3.1).

9.3.2 Experimental Procedures - Tyre 5 Energy Balance

External observations were made of the building exterior, thermograms being taken of the lower and upper portions of the wall.

Figure 9.3.1. Thermographic Investigation Of Fort Dunlop

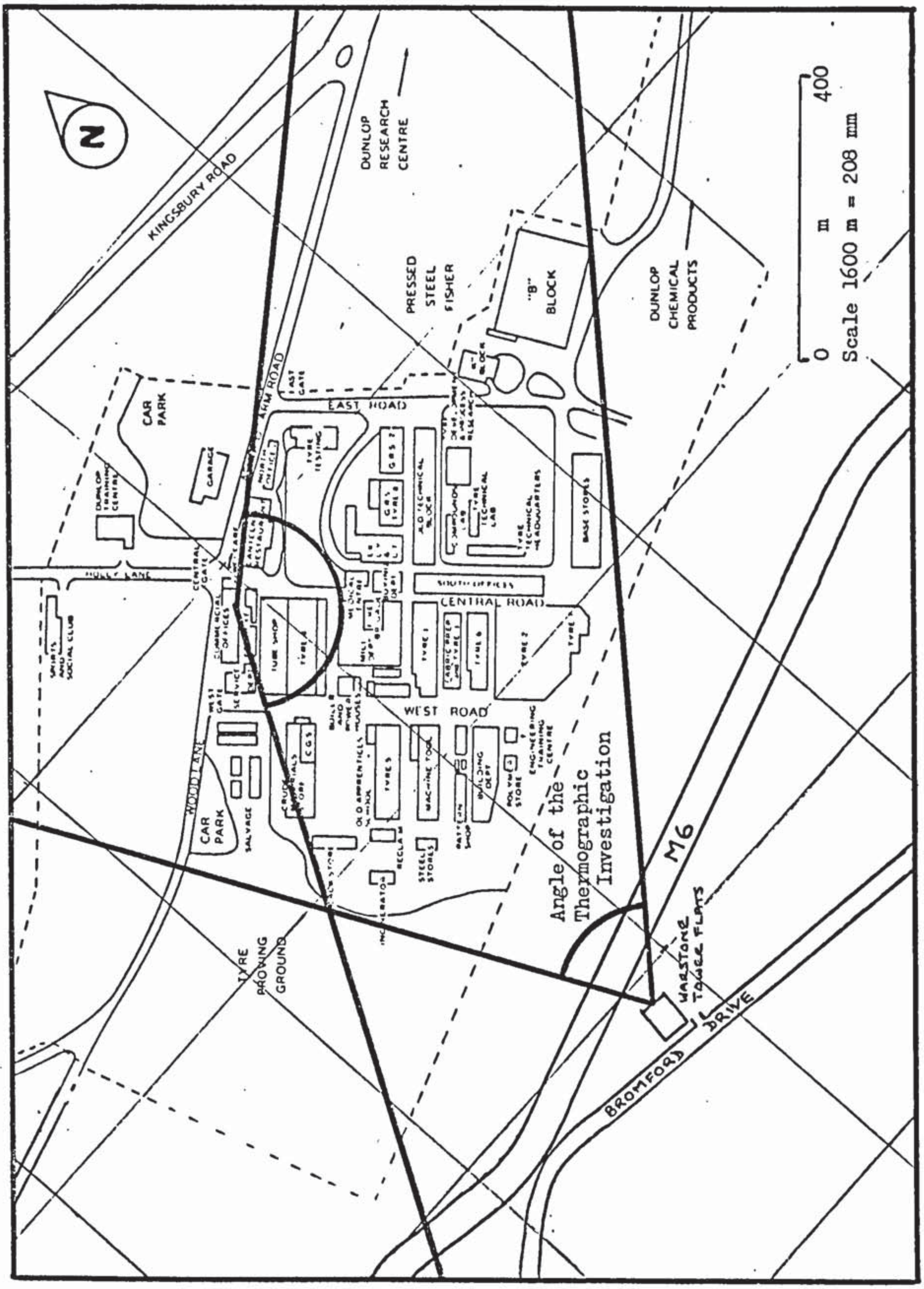


Table 9.3.2 Conclusions Drawn from temperature Recorder Recalibration

a. Sunlight had a marked effect when shining directly on the sensing element thus causing peaking and increasing the average measurement over a period. Such peaks had local amplitude in excess of 6C.

b. Wind appeared to be the cause of the step changes although direction and speed showed little effect upon the average daily temperature. Stepping was more pronounced on colded dull days.

c. The close environment tended to affect the temperature plot through moderation of rate of changes.

d. The recordings made during the thermovision studies were verified as being suitably accurate.

The thermographic procedures were those as described in Chapters VI and VIII, with the notable inclusion of a reference temperature source. This constituted a tin can, coated with matt-black emulsion paint, and filled with water of known temperature. The emissivity of the can was taken to be >0.91.

Additional measurements of internal building temperatures were taken using four suitably placed chart recorders (See figure 9.4.14), each of which had previously been calibrated. (350). In equilibrium, each meter exhibited an accuracy of $\pm$ 1°C. During the run of the thermal study, however, chart recorder (No. 7953) produced anomalous step change, contrasting with the continous curves of the others. It was, therefore, necessary to verity the results obtained through further calibration studies (351). The conclusions drawn are given in Table 9.3.2.

In conjunction with interior temperature measurement, the following measurements were also recorded:

- Inlet and outlet cooling water temperatures, prior to and after the experiment;
- Departmental steam consumption and properties at half hour intervals;
- Relative humidity at hourly intervals;
- Local wind speeds and directions at the position of each thermogram;
- General ambient weather conditions from the Meteorological Office, Birmingham Airport;
- Spot and reference temperatures;
- Tyre production output.

All measurements and readings were duly recorded on previously compiled data-record sheets (352) (353). The experimentation was carried out on Tuesday 12th July, 1977. Additional 'air change' measurement studies were initiated directly from the results of the thermographic study. These were carried out on Wednesday 24th May, 1978.

9.3.3 Experimental Procedure - West Road Steam Main

The standard thermographic techniques were adopted in making observations of heat dissipation from the 350 psi. steam main on the West Road. Positions of study and content of each thermogram are given in Figure 9.5.6. The reference temperature was taken to be that of the atmosphere. For verification of the emissivity of the aluminium cladding, a similar reference to that described in Section 9.3.2. was used. Additional measurements included:

- Continuous measurement of steam discharged from the boiler house to the main
- Average temperatures and pressures of steam
- Continuous measurement of steam flowrates into each department or branch main.
- Continuous record of ambient air temperature
- Local wind speeds and directions
- General weather conditions from Birmingham Airport
- Spot and reference temperatures

All measurements and readings were recorded on the previously prepared data logging sheets (352) (353). Initial experimentation was conducted on Tuesday 23rd August, 1977 but due to the effects of reflected solar radiation studies were repeated on Wednesday

28th September, 1977. In addition to the original objectives, therefore, the effects of reflection of atmospheric radiation were consequently assessed.

9.3.4. Experimental Procedures - Site Surveys

Observations of hot-spots and roof temperature variation were made using the remote thermographic procedures already described. Two scans of the entire Fort Dunlop Site were made, the first on Monday 11th July 1977 from the top of the Warstone Tower Flats, and the second on Wednesday 24th August, 1977 from the top of the Commercial Offices building. Figure 9.3.1 depicts the fields of view.

The adopted reference temperatures were those of the atmosphere, grass and trees taken to be at ambient. All primary and secondary energy flows together with water consumptions were measured into and throughout the factory site so as to provide a basis for a possible energy balance. Measurement of local wind speed and ambient temperatures were also recorded, with general weather conditions obtained from the Meteorological Office Birmingham Airport.

9.3.5 Interpretation of Results

Measurement of surface temperatures proceeded directly from the position of each isotherm marker shown on the bottom of the thermograms. As in the previous chapters, isotherm levels (i_e) were deducted from multiplication of these values with the sensitivity.

Due to the complexity and variation in emissivity of the surfaces being viewed, it was assumed that for the Tyre 5 energy balance and the site surveys, all surfaces exhibited black body characteristics. For the West Road steam main, however, additional measurements of surface temperature, using a conventional thermocouple, were taken so as to establish the value of emissivity for the aluminium cladding. Equation - 4, given in Chapter VI was then used to ascertain the absolute isotherm units and hence the temperature.

With lower emissivities, equation - 1 would have been more suitable for computation. The critical measurements required for its use, however, were not recorded at the time of experiment.

The establishing of actual temperatures, with respect to some reference utilised the standard AGA graphical procedure described in Chapter VI . For low isotherm values, the accuracy the established temperature was in doubt, since interpolation was based on the flatter section of the curve giving a large change in temperature for a small alteration in isotherm level.

For results appertaining to remote sensing of the site as a whole, it was assumed that at most, attenuation could only influence isotherm values by a maximum of 10%. Consequential effects on temperatures were for the most part $< 10\%$ except for low values of isotherm units. No account was therefore made for attenuation, since values obtained were relative to a reference temperature of an object of a similar distance, thus providing a comparative result.

Table 9.3.3 Abbreviations Used

Thermograms	DB	-	dark blue
	LB	-	light blue
	G	-	green
	P	-	pink
	R	-	red
	Y	-	yellow
	W	-	white
Fort Dunlop Site	CO	-	Commercial Offices
	BH	-	Boiler House
	NM	-	New Mill
	MT	-	Machine Tool
	PH	-	Power House
	Grind	-	Grinding Shop
	FPD	-	Fabric Preparation Department
	CPD	-	Compound Preparation Department
	NO	-	North Offices
	TH	-	Test House
	LY&LT	-	
	RC	-	Rubber Components
	OTB	-	Old Technical Block
	THQ	-	Technical Head Quarters
	SO	-	South Offices
	TD&PR	-	Tyre Development & Product Research
	HB	-	'H' Block
	BB	-	'B' Block
Others	L	-	Maximum Local Wind Speed - m/min.

A number of abbreviations have been included in the calculations, descriptions and tables. The legend for these is given in Table 9.3.3.

9.4 Records and Results - Tyre 5 Energy Balance

9.4.1 Introduction

Measurements were made of a number of critical input and output energy flows/properties, ambient weather conditions, internal temperatures, and production activity for the Tyre 5 building. Records of these are given in Appendix C.1 - Tables C.1 to C .6.

A number of thermograms were produced for heat dissipated through various sections of wall, at both low and high level from local sensing, and of the roof from a remote sensing position on top of the Warstone Flats (Figure 9.3.1). These are depicted in plates 9.4A to I (Appendix C); description of each, together with calculations of black body temperatures, being given in Figure C.7.

Resulting from initial evaluations of heat loss, additional investigation of heat loss through building air change was carried out. The documented data for this work is given in Appendix C.2 - Tables C.8. to C.13. Summary of locations of thermograms, positions of measurements for air velocity and general layout of the production area are shown in figure C.14; positioning of temperature recorders also been given.

Computation of the results are given in section 9.4.2. - thermographic findings; and section 9.4.3. - air change findings; with concluding remarks and comments documented in section 9.4.4.

9.4.2 THERMOGRAPHIC ENERGY BALANCE - TYRE 5

a) Energy Content of Steam

Average hourly flow rate during period	-	8320 kg/hr
Average Pressure	-	24.4 bar
Average Temperature	-	278.3 °C
Enthalpy of steam at these conditions	-	2960 kj/kg
Total energy in steam to Tyre 5	-	24627 Mj/hr

b) Energy Content of Electricity

Average hourly consumption during period	-	187.7 Kwhr/hr
Total energy in electricity to Tyre 5	-	675.7 Mj/hr

c) Energy Content of Product

Average hourly output during period - 2820 kg/hr

Average energy used in tyre manufacture (Ref. P Dufton - (16))

Making = mass x 510000	-	1438 Mj/hr
Moulding= mass x 217400	-	613 Mj/hr

The majority of energy utilised before moulding is consumed outside Tyre 5. Moulding energy requirements are therefore considered.

Total energy content of tyres produced - 613 Mj/hr

d) Energy Loss to Atmosphere from Cooling Tower

Estimate of water flow rate to tower (based on pump size) - 54.55 m^3/hr

Mass flow rate	-	54462.7 kg/hr
Average input-output temperature difference	-	7.8 ^oC
Average specific heat of water	-	4.18 kj/kg ^oC
Total energy loss up cooling tower	-	1777 Mj/hr

e) Energy Content of Condensate

Estimated condensate collected from Tyre 5 (65% of that returning to Tyre 1 pit)	-	5.6 m^3/hr
Mass flow rate	-	5408 kg/hr
Specific heat of condensate	-	4.20 Kj/kg^oC
Total energy returned in condensate	-	2012 Mj/hr

f) Heat Dissipation from Walls - as Measured by Thermograms

The equations used to determine heat loss from walls were those defined in Figure 6.5.7, Chapter VI.

Emissivity of all surfaces assumed to be	-	1.0
Average wind speed over building	-	269 m/min
Ambient temperature	-	15.3 ^oC
Average temperatures for walls:	Maximum -	26 ^oC
(note this excludes high spot values)	Minimum-	19 ^oC
	Average-	22 ^oC
Heat loss by radiation (Qr) -	Maximum-	0.223
Mj/m^2.hr	minimum-	0.068
	Average-	0.138
Heat loss by convection (Qc) -	Maximum-	1.700

$Mj/m^2.hr$	minimum	-	0.537
	Average	-	1.074
Total area of walls		-	2298 m^2.
Total heat loss from walls (Qt)	Maximum	-	4419
Mj/hr	Minimum	-	1390
	Average	-	2785

g) <u>Heat Dissipation from Roof - as measured by Thermograms</u>

As above, the equations used were those defined in Figure 6.5.7.

Emissivity of all surfaces assumed to be - 1.0

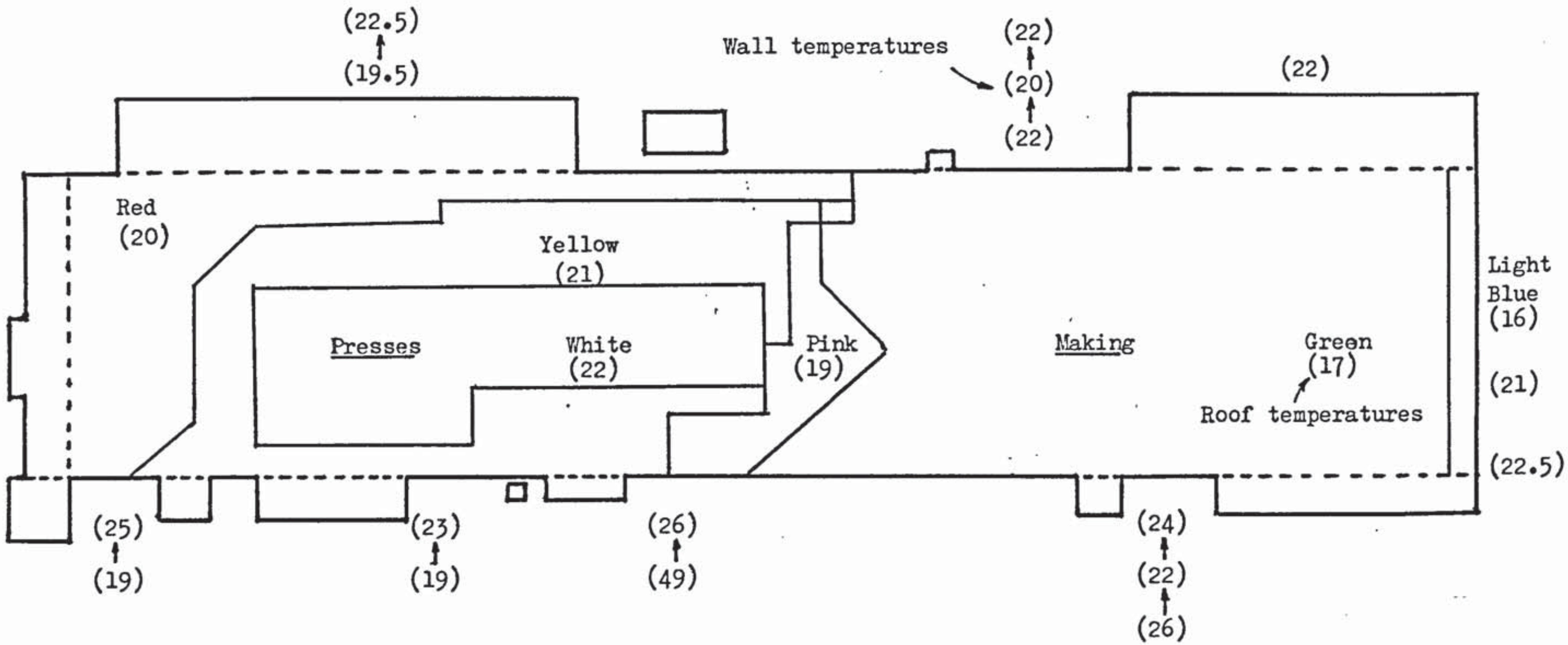
Average wind speed over building - 269 m/min

Ambient temperature - 15.3 ^{o}C

Calculations of heat loss are summarised in Table 9.4.2. based on areas estimated from Figure 9.4.1

Total heat loss from roof - 3266 Mj/hr

Figure 9.4.1 Tyre 5 Temperature Distribution from the Thermograms



Temperatures in C

Total Area of Roof = 6441.5 m^2

Production Roof Area = 4994.0 m^2

Press Area = 2943.1 m^2

Total Area of Walls = 2298.5 m^2

Table 9.4.3 SUMMARY OF TYRE 5 ROOF HEAT LOSSES

	Temp °C	Area m^2	Qr Mj/m^2hr	Qc Mj/m^2hr	Qt Mj/hr
	22	701	0.138	1.074	850
	21	1013	0.114	0.895	1022
	20	706	0.091	0.716	570
	19	226	0.068	0.537	137
	17	2239	0.034	0.268	676
	16	109	0.011	0.089	11
TOTAL	-	4994	-	-	3266

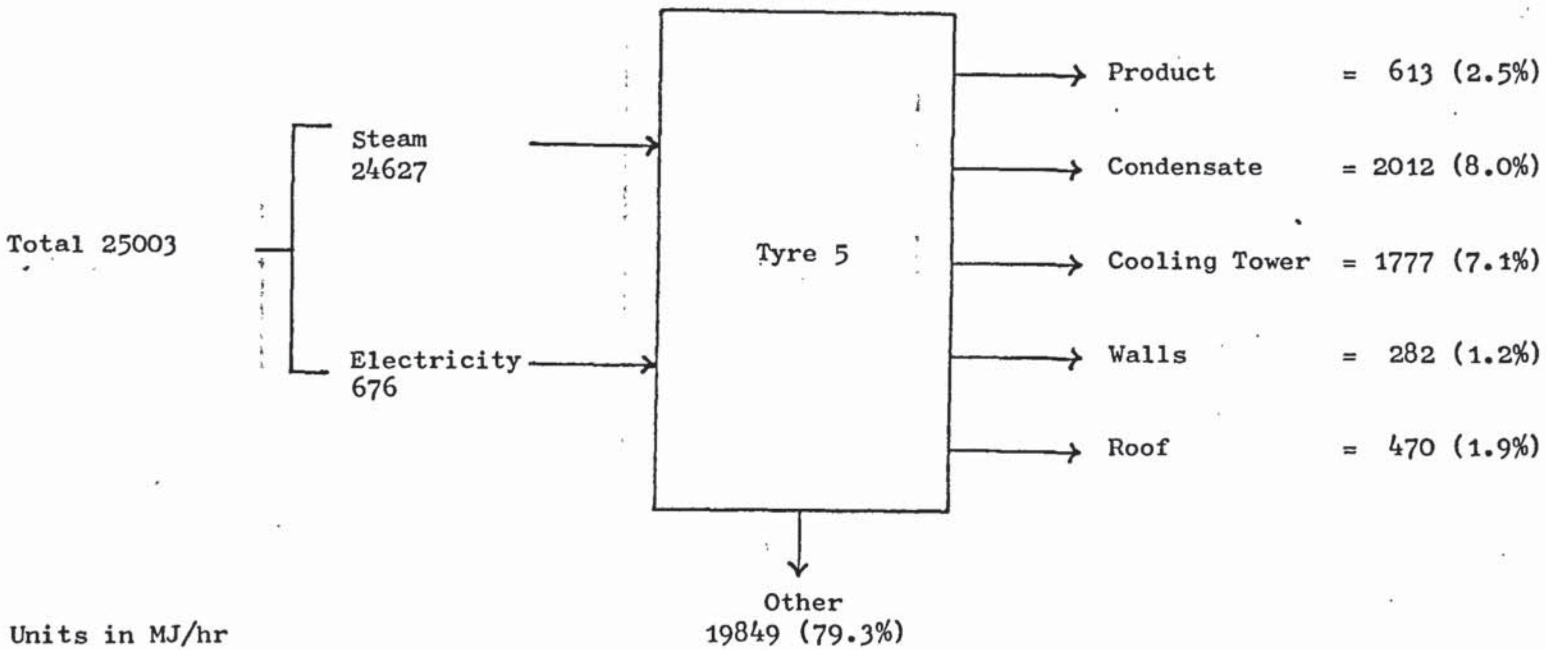
h) <u>Heat Dissipation from building - as measured by Thermograms</u>

Maximum	-	7685 Mj/hr
Minimum	-	4656 Mj/hr
Average	-	6051 Mj/hr

i) <u>Energy Balance</u>

Figure 9.4.4 Summarises the energy balance for Tyre 5 based on Thermographic measurements.

Figure 9.4.4b Comparative Summary of Energy Balance Tyre 5 - Based on Calculations from 'U' Values



Units in MJ/hr

Comment

- Assumptions - normal standard conditions.
- Using 'U' Values, calculation of heat loss through the building fabric depicted a lower significance in establishing an energy balance than the thermographic technique. This may be due to inaccurate internal temperature measurements.

9.4.3 ENERGY LOSSES IN AIR CHANGES - TYRE 5

a) Energy Content of Steam

Average hourly flowrate during period	-	6714	kg/hr
Average pressure	-	22.4	bar
Average temperature	-	278.3	^oC
Enthalphy of steam at these conditions	-	2960	Kj/kg
Total energy in steam to Tyre 5	-	19873	Mj/hr

b) Energy Content of Electricity

This thermal contribution to heat lost through air change was estimated to be less than 2.6% of that for steam and was therefore ignored.

c) Energy Content of Product

As in the case of electricity, the energy retained by the product was approximately the same and therefore ignored.

d) Energy Loss to Atmosphere from Cooling Tower

Estimates of water flow rate to tower	-	54.55	m^3/hr
Mass flow rate	-	54462.7	kg/hr
Average input-output temperature difference	-	4.2	^oC
Total energy loss up Cooling Tower	-	956	Mj/hr

e) Energy Content of Condensate

Estimated condensate collected from Tyre 5 (65% of the steam input to Tyre 5) - 4.37 m^3/hr

Mass flow rate	-	4226 kg/hr
Total energy returned in condensate	-	1455 Mj/hr

f) Heat Lost in Air Change

Internal temperature of building -

	Minimum	Maximum
-	$18^{o}C$	$38^{o}C$

Ambient Air Temperature - $12^{o}C$

Differential Air Temperature	Minimum	Maximum
	$6^{o}C$	$26^{o}C$

Specific heat of air - 1.274 $kj/m^{3o}C$

Volume of building - 27861 m^3

Sum of air flow rates into building (excluding windows, ventilators etc.) -

	Minimum	Maximum	Average
in m^3/ hr	114624	147744	131184
Least air changes/hr	4.1	5.3	4.7

Heat losses through air changes -

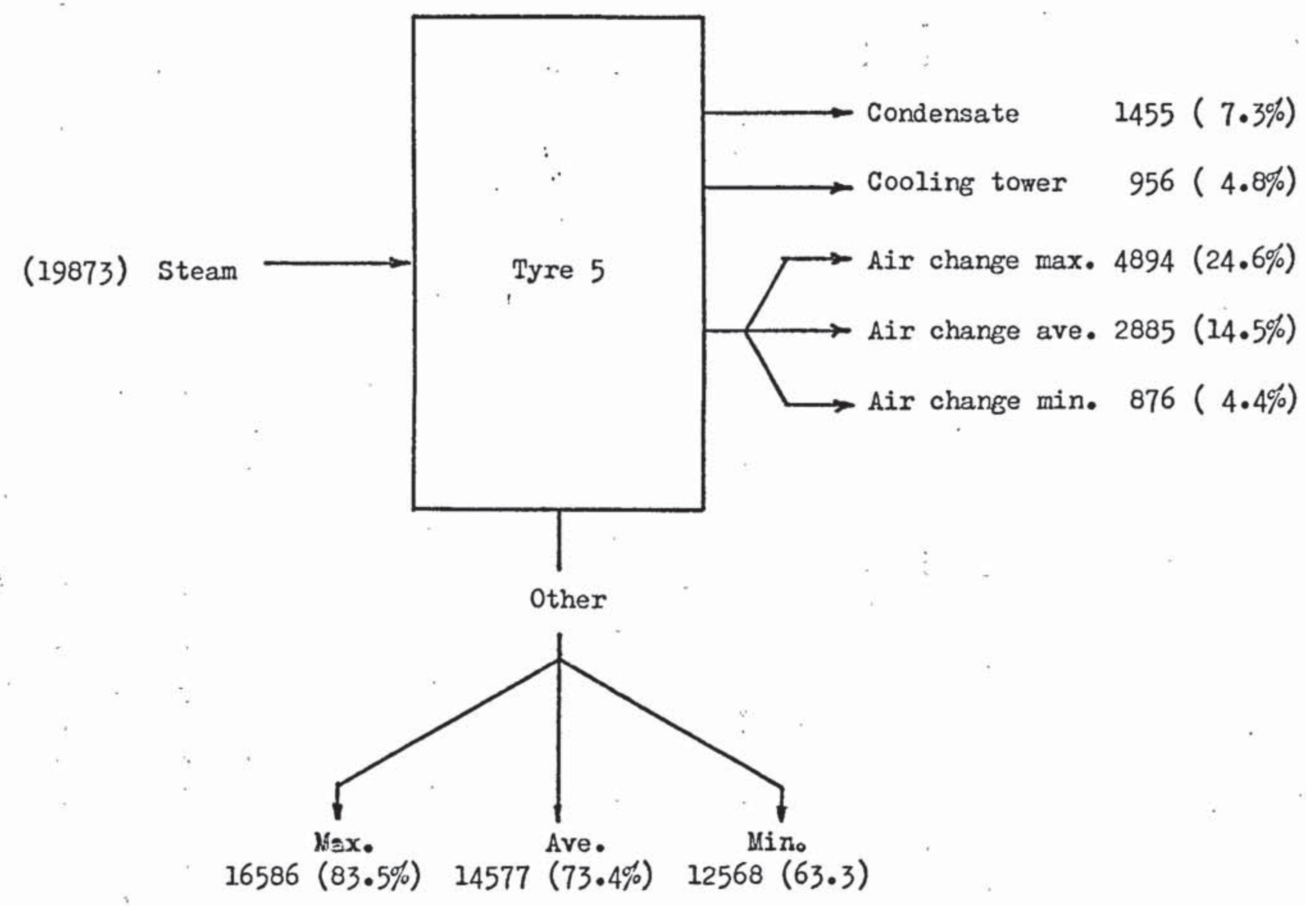
	Minimum	Maximum	Average
in Mj/hr	876	4894	2885
% of 19873 Mj/hr input	4.4	24.6	14.5

g) Energy Balance

Figure 9.4.5 Summarises the energy balance for Tyre 5 accounting for an average air change of 4.7 per hour.

Figure 9.4.5. Tyre 5 Energy Balance Summary Based on Air Change

Units = MJ/hr.



9.4.4. Concluding Remarks

The principal aim of this work was to establish the viability of employing thermographic surveys of buildings in determining quantitative values of the energy consumed within, and ultimately the energy balance. With a true balance, identification of areas of misuse would be simplified.

Returning to figure 9.4.4 , the resultant quantity of energy measured by the thermograms was both small and disappointing. At best, only 30.8% was measurable,with deviation from the average being as high as ± 25%. In total, the heat retained by the product, the heat in condensate, and the losses up the cooling tower summed a further 17.6%. Assuming the average values, this meant over 57.4% of the energy entering the building was left unaccounted.

Initial conclusions led to the belief that the main portion of this energy was lost through air-change, ventilation and extraction. Experiments showed, however, that the air-change was probably a minimum of 4.1 an hour and a maximum of 5.3 an hour. This experimentation, however, was inconclusive due to the difficulties in measuring all the air flows concurrently, and the unreliable method of attaining average values for velocity through the openings. If it was assumed that even this maximum value could in reality be 50% inaccurate, 51% of the energy would still be classed as 'other' in figure 9.4.5., of which at best only 30.8% would be thermographically measurable. This still left 20.2% unaccounted loss.

There were a number of explanations to this predicament:

a. Measurement of energy inputs and outputs could have been subject to error. This was particularly true for the assessment of condensate return flow. Naturally all steam condensed sooner or later, but calculation was in doubt of the percentage condensed returned, to that lost to drain, to that flashed to atmoshpere, to that exhausted to the heating main for use in other parts of the factory. Similarly, no allowance could have been made for steam leaks. It was believed that this could have contributed greatly to the missing 20%.

b. No account was made for the energy input to the building in water, compressed air or human emission. Whilst these were likely to be small, the heat content of water existing in the building was very possibly large and of course unmeasurable through inaccessability.

c. It was assumed that the temperature of the green covers or materials entering the building were at the same levels for finished tyres and scrap leaving the building. Such assumption might have been incorrect, since rubber tended to take long period to cool from vulcanisation temperatures and consequently a greater amount of heat may have been retained by the product exported. Whilst this was ultimately lost to the atmosphere, it could have been measured as temperature at the point of exit.

d. It was difficult to associate isothermal values with actual roof areas and wall sections. Large errors may have resulted here.

e. Actual emissivities were undoubtedly less than unity ($\simeq$0.9). The effect on final heat loss calculations, therefore, could have been significant at these low temperatures. Emissivity correction would have increased the isotherm values, which at low temperatures, would have produced a significant swing in temperature measured. This would have given higher values of Qc, similar values for Qr (emissivity loss being offset by temperature gain), and consequent higher values of heat lost. However, uncertainties in accurately measuring emissivity led to its omission.

f. Changes in wind velocity would have greatly affected Qc. It was impossible to establish actual local velocity over the roof or along the walls, but a variation of 10% to speed recorded could have produced a 12% differential to heat lost. Whilst average values given at Elmdon Airport would have been suitable for roof calculations, the effects at the walls would have been less certain.

g. Measurement of roof temperatures were assessed from a remote position. At 1000 m the attenuation could be reduced by as much as 10%. The higher temperatures at the 26°C level would have meant an increase of 22% on Qr and 21% on Qc, giving an overall increase of 21%.

The results obtained lead to the indisputable opinion that not only is thermography incapable on its own of accurately assessing the energy balance for a building (due to unaccountable loss), but also that it is impossible to find credence in the heat losses calculated from the thermograms due to effects of wind, emissivity, assessment of isothermal surface areas, unreliabily of calculation etc. It is unrealistic, therefore, to establish U values for a building under these conditions. Similarly it is unlikely that reliable quantitative data of heat loss can be established by measuring energy inputs and proportioning losses according to the isotherm indicated in the thermograms.

It must, therefore, be concluded that outside the confines of more rigorous environmental control of conditions, thermography can at best only provide qualitative information on heat loss from buildings, with only tentative reliability being attributed to actual values. The attaining of the energy balance must be deemed ambitious.

9.5 Records and Results - West Road Steam Main

9.5.1 Introduction

Measurements of wind speeds, ambient temperatures, steam conditions and a number of critical flow rates were recorded. These are documented in Appendix D.1 :- Tables D.1 to D.2; and Appendix D.2 : - Tables D.3 to D.4. Initial investigations were carried out on 23rd August, 1977. The bright-sunny conditions, however, tended to produce significant levels of reflected radiation particularly from surfaces having low emissivity. Subsequent inaccuracies in thermographic temperature measurements resulted. Consequently the investigation was repeated under overcast conditions on 28th September, 1977, providing more accurate thermograms as well as a significant contrasting picture of the effects of reflected atmospheric radiation. Both sets of thermograms are given in Plates 9.5A to K (Appendix D), temperature calculations and descriptions being recorded in Table D.5.

Figure D.6 identifies the position of each thermogram.

Based on the findings of past experimentation, the widespread use of aluminium cladding on steam distribution systems proved a need to assess the value of its emissivity. This was estimated at 0.31.

The results obtained and the conclusions drawn are given in Sections 9.5.2. with the resultant thermal flow rates, thermogram positions, dimensions and calculated temperatures depicted and summarised in Figure 9.5.3.

9.5.2 Observations of Thermograms and Results

a. Plates 9.5A and 9.5B

There were pointed indications of hot spots present at the Tyre 7 take-off point, where flanges were unlagged and heat was conducted to atmosphere through the valve chassis. Estimates of the real temperature of the main at this point were put at 28-30°C. Contrasting temperature measurements made during the sunny conditions were 55°C, emphasising the servere effects of atmospheric radiation. Contrasting values for the air main were 23°C and 32°C respectively.

b. Plate 9.5C

Unlagged pipework, hot valves etc were clearly identifiable. Also shown were the concentration of higher temperatures at pipe joints, where cooling was less effective, and the relative cooler 152.4mm (6") ∅ Section compared with the 203.2mm (8") ∅ Section. Estimates for these were 33 and 36°C respectively. In contrast, the measurements under sunny conditions were 55°C for both diameters. For the air main in sunny conditions, temperatures on some of the upper surfaces were 52-63°C and the remainder plus the bottom surfaces at 41°C. This demonstrated the inadequacy of analysis under sunny conditions.

c. Plates 9.5D and 9.5E

Accepting the identification of hot spots, there appeared to be a large variation in measured temperature from the upper to lower surfaces of the pipe (28-30°C). Significantly these contrasted with the measurement of 55°C for sunny conditions. The air main subsequently showed a variation of 23°C compared with 41°C for sunny condition. Once again in D2 variation of 58-28°C was found from top to bottom of the air main. An interesting qualitative observation in D2 was the heat dissipated from the steam pipe to the gantry framework through the anchor-plage.

d. Plate 9.5E

The temperature of the main at the point of the Tyre 6 take-off was estimated at 28°C. Hot spots were identified at the valve and anchor-plate positions.

c. Plate 9.5F

From an inadequately reproduced thermogram, measurement of surface temperature was put at 23°C. Hot spots were also identified on the F.P.D. Steam Station.

f. Plate 9.5G

Measurements at the T1 take-off gave the cladded steam main temperatures at 33°C and an unlagged pipe temperature at 216°C (Steam temperature at this point estimated to be that of saturation = 217°C). This demonstrates the relative accuracy of temperature measurement.

g. Plate 9.5I

The most significant feature of this thermogram was the heavy loss dissipated from the pipe to the gantry support. The temperature of the main was put at 28°C.

9.5.3 Concluding Remarks

The temperatures of the steam main were found to vary between 23°C and 36°C along its entire length. There was no clear pattern or apparent reason for these changes,unless variation could be attributed to the effectiveness of the lagging thickness and properties relative to the various pipe diameters. There also appeared to be concentrations of temperature near exposed hot surfaces and in the corners of joints, caused by conductive / radiative effects and reduced effective cooling respectively.

As with previous experimental findings, identification of hot spots was simple and quick. In this case, however, with aluminium being of low emissivity, care had to be exercised when comparing the isotherms of this metal with those of other materials, i.e. the gantry. With respect to qualitative analysis, however, the outstanding conclusion was the unreliability to the thermogram in conditions of substantial 'atmospheric' radiation from the sun. Under bright sunny conditions, reflected radiation from surfaces produces anomalous results, rendering thermography completely inadequate.

Measured skin temperatures of the steam main were found to be substantially higher than those rendered by the thermograms. This confirmed fears that under normal factory conditions quantitative measurement of low emissivity surfaces was subject to error. In contrast, measurements for high emissivity surfaces - mild steel pipe - were relatively reliable. Sunny conditions only excentuate any discrepancy. Reasons for this disappointing conclusion include:

- Inadequate measurement of reference temperature
- Inability to accurately account for all the influencing factors, thus enforcing the use of equation - 1 in preference to equation - 4.
- Unreliable estimation of emissivity.

Singularly, it is this last point which is believed to provide the largest effect.

As a consequence of inaccurate surface temperature measurement, heat loss from the various diameter pipes could not be assessed and subsequent loss relative to thermal flow calculated. The establishment of an energy balance based on thermography was, therefore, deemed improbable.

With the majority of insulation cladding being of low emissivity, with many distribution systems being in the open-air, with the problems of estimating the additional cooling effects of the wind etc, and with the difficulties and inaccuracies of computing the results, thermography must be declared impractical, not only as a means of quantitative determination of energy losses in a distribution system, but also a qualitative assessment device.

9.6 Records & Results - Site Surveys

9.6.1. Introduction

Measurements were recorded of wind speeds, ambient temperatures, steam conditions, and a number of critical energy flow rates into the factory and within the site boundaries. These are documented in Appendix E.1 . - Table E.1. for thermograms taken on 11th July, 1977 and 24th August, 1977.

The procedure adopted remote sensing from the two positions given in Figure 9.3.1., namely the Warstone Flats and the Commercial Office Block. From both positions, all buildings observed were within a 1000m radius, thus limiting transmissivity loss to a maximum of 10%. The general ambient conditions for both days were overcast, giving minimum atmospheric radiation gain.

Due to the vastly varying surface emissivities, a unit value was assumed. Reference temperatures were obtained from assumption that grass, trees and the atmospheric background were at the ambient temperature. The results of each thermogram, shown in Plates 9.6A to 9.6W (Appendix E) are recorded in Table E.2. Section 9.6.2. provides a summary of the observations made, and Section 9.6.3. the overall conclusions.

9.6.2 SUMMARY OF OBSERVATIONS

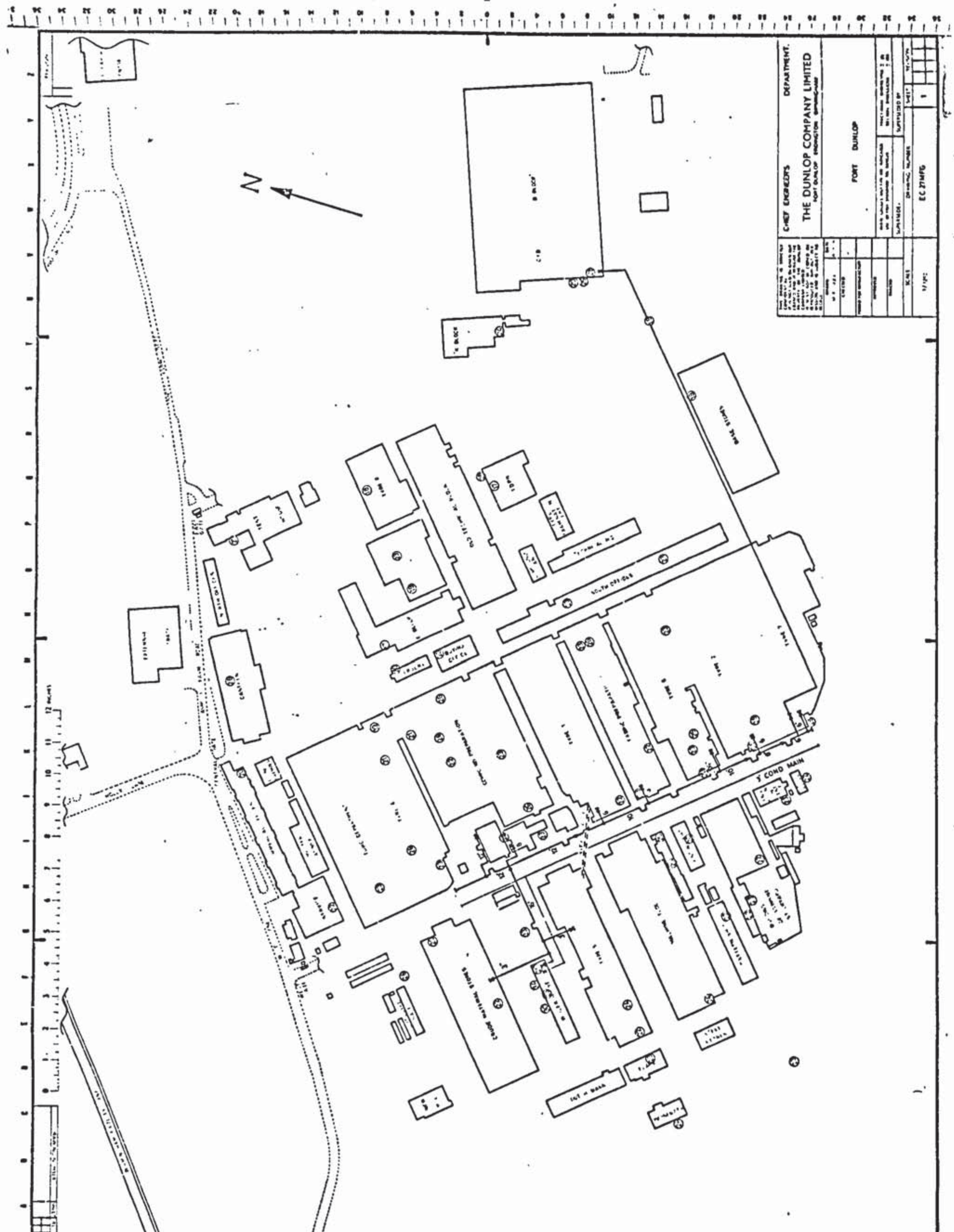
The following observations have been made directly from interpretation of each thermogram; hot spots etc being identified and the relevant temperature recorded. A summary of the hot spots is charted on the site layout figure 9.6.1.

Plate No's 9.6	Photo No.	Description of Hot Spots	Colours	Temperature Measured °C
A	B 3	- Incinerator stock and flare	Y-W	23-25
	B 4	-'Heavy-gang' rest room roof and door	R-Y	22-23
B	B 9	-'Steel-erectors' rest room roof	R-Y	22-23
C	B 8	- Machine tool toilets roof	R-W	22-25
		- Flaps roof	R-Y	22-23
		- T.5 Toilets. roof	R	22
		- T.5 moulding roof	R-W	22-25
		- Boiler house roof	Y	23
		- C.M.S. roof	R	22
	B10	- Stacks and flares	R-W	23-30
		- Boiler house roof	R	23
D	B11	- Boiler house roof	Y-W	23-25
		- Deaerator building	R-Y	22-25
		- Service building	R	22
		- C.M.S. roof above steam main	R	22
		- Pattern shop furnace roof	R	22
	B14	- T.4 Moulding roof	Y	23
E	B12	- Pattern shop and furnace roof	R-Y	22-23
		- Building stores	R-Y	22-23
		- Steel erectors roof	R-Y	22-23
F	B17	- Commercial office toilets walls	P	20
		- C.P.D. roof	P-W	20-25
		- Oil storage tanks	Y	23
		- T.1 Workshop roof	P-R	20-22
	B18	- F.P.D. Steam station	R-Y	22-23
G	B16	- Grinding shop roof	R	20
		- Internal transport roof	R	20
		- Internal transport roof above steam pipe	Y-W	23-25
		- Building workshops and stores	R-Y	20-23

Plate No's 9.6	Photo No.	Description of Hot Spots	Colours	Temperature measured °C
G	B19	- Building stores roofs	R-Y	22-23
H	B22	- F.P.D. dipper-drier stack	R-Y	22-23
		- T.6 moulding roof	R-Y	22-23
	B21	- T.6 pump room walls & roof	R-Y	22-23
		- Pump room door	+W	+25
		- F.P.D. roof	P-R	20-22
		- Mill far wall	R	22
I	B23	- T.6 moulding roof	R-W	22-25
	B20	- Training centre toilet roof	R-Y	22-23
		- Oil stores	R	22
J	B24	- T.2 Steam station	+W	+25
	B27	- T.7 Steam station	R-W	23-30
		- T.2 Moulding roof	R-W	23-30
		- Roto cure roof	R	23
		- South office block	P-R	20-23
K	B28	- 'B' Block ground floor	P-R	20-22
L	E1&E2	- Boiler House stacks and flares	P-W	26-34
		- Incinerator stack	LB	18
M	E3	- Unlagged flange/Pipe to Salvage	P	26
	E4	- Steam pipe behind C.M.S. wall	P	20
		- Tube moulding roof	R-Y	21-24
N	E5	- T.4 moulding north lights roof and vents	R-+W	21-+26
		- Deaerator building and boiler house roof	R-+W	21-+26
	E6	- T.4 moulding roof etc	R-+W	21-+26
O	E7	- East wall T.4 moulding	R-+W	21-+26
P	E9	- Pump room/Compressor house	R-+W	21-+26
		- Steam valve grid	+W	+26
		- C.P.D. roof above warming cellars	R	21
	E10	- Door to C.P.D. upper floor	R	21
		- Exhaust ducting F.P.D. drying ovens	R	21
Q	E11	- Door to C.P.D. upper floor	R	21

Plate No's 9.6	Photo No.	Description of Hot Spots	Colours	Temperature Measured °C
R	E12	- Door to C.P.D. upper floor	W	26
		- Vents from C.P.D.	R	21
	E23	- Vent above T.4 extruders	R	21
S	E13	- C.P.D. north lights and stack	R-+W	21-+26
		- Corridor C.P.D. roof above heaters	W	26
		- Dipper stack F.P.D.	+W	+26
T	E14	- Corridor C.P.D. roof above heaters	+W	+26
U	E15	- Buying dept. steam and condensate grid	P-+W	17-+20
		- Pumping trap Technical Head Quarters	W	20
	E16	- Instruments north light	Y-W	19-20
		- Steam and condensate coils in corridor	R-Y	18-19
		- Calorifiers medical centre & valve grid	R-W	19-20
		- Firemens store	P	17
		- Base Stores heaters and steam mains	Y	19
V	E17	- Rubber components north lights, vents	R-Y	18-19
		- Curing bag heaters	R	18
		- T.D.P.R. vents, north windows	P	17
		- 'B' Block steam main	P-W	17-20
		- T.D.P.R. pump room	P-W	17-20
	E18	- 'B' Block cyclone extraction	P	20
		- Atmospheric steam vent	+W	+26
		- Heating mezanine floor	P-R	20-21
		- Cold calender GRSI roof light	R-Y	21-24
		- Hot water facility K Block	Y	24
		- T.D.P.P. hot water plant	R-+W	21-+26
		- Training office heaters	R	21
		- Heating for creel room	R-Y	21-24
W	E19	- T.8 Doors and windows	R	18
		- T.8 moulding roof windows	R	18
	E20	- Canteen extractors, roof lights etc	R-+W	21-+26
		- Hot water pipe, test house	R	21

Figure 9.6.1 Charted Summary of Hot Spots



9.6.3 Concluding Remarks

Any question-marks levelled at the effective use of thermography in identifying heat loss purely in a qualitative capacity have been dispelled as a result of this exercise. Pipes and valves unlagged, hidden heat loss behind walls or under roofs, hot air extraction; poor U Valves, open doors and windows, or hot process areas can readily be detected by remote sensing.

Surfaces having low emissivities, however, present a problem. Unlike localised thermograms, where the value of emissivity can be assessed albeit inaccurately, remote sensing may fail to even identify such a surface. An example of this occurs in B11 of Plage 9.6D, where the heated oil storage tanks are not identifiable since they are clad with an aluminium sheeting. In contrast, those in B17 of plate 9.6F have no cladding and are shown as yellow. This concludes that even for qualitative analysis an experienced eye is still required.

Results from the Tyre 5 energy balance experiment, in which only one building was studied, indicated that attainment of the energy balance for a whole site would be difficult if not impossible. The accuracy of quantitative data of building plant heat loss based on thermographic evidence has already been shown to depend on many factors including emissivity, attenuation, wind speed, estimates of surface area etc. Consequently, attempts at an energy balance were omitted. Based on the assumption that heat loss is proportional to surface temperature, it may be possible to apportion energy use or misuse according to the temperature profiles of the site and assuming accurate measurement of energy inputs. This naturally assumes that all energy is given off as heat from the surfaces being viewed. In practice this is unlikely to be true, since the majority of heat is believed to be lost either to the atmosphere as hot air, or down the drain as hot water. Detection of these is not easily achieved. This might, however, become a subject for future research.

The whole crux of remote sensing on factory sites relies on the availability of a high building or point of observation. Many sites do not have this facility, in which case the only answer is an aerial survey. Whilst both may indicate the pattern of heat distribution on the site, only surfaces actually being viewed will contribute to the thermal picture. For example, it is impossible to estimate or see the heat being lost from all walls. Consequently this calls for additional thermographic monitoring by circum-navigation of the buildings on the site. A roving camera on suitable transport may be the answer.

However, the conclusions bear out the initial hypotheses that whilst site surveys have their place in the initial investigation, they must be followed by successively more detailed local investigation of the problem areas identified. The catch phrase might well become 'Homing in on the hot spots'.

9.7 Concluding Discussion

With the initial objective to establish the practical feasibility of the use of thermographic techniques for the qualitative assessment of thermal efficiency and/or heat loss, this work conclusively shows that as a means to identifying inefficiency, the standard thermogram holds great potential. An energy engineer conversant with interpretation of the thermogram and the objects being viewed can readily inspect large quantities of plant, equipment and buildings from remote positions, and in a relatively short time period, thus determining ineffective performance in energy utilisation which might otherwise remain undetected.

Quantitative analyses, first of temperature and later heat loss, are not so easy to achieve and are of questionable accuracy. Problems include:

- the requirement of additional measurement such as a reliable reference, spot and ambient temperatures, energy flows and conditions etc.
- identification of and allowance for low emissivity surfaces (for many industrial objects > 0.9 may be assumed)
- complexity of dimensions and surface areas being viewed
- large variation in temperature differentials
- presence of reflected radiation effects
- presence of attenuation effects for remote sensing
- increased computation needs of results for non-ideal surfaces.

In complete contrast to the success of thermographic techniques as a qualitative tool for identifying potential energy savings, quantitative analysis in the real industrial environment departs from the rudiments of simplicity. In controlled laboratory conditions, there is significant scope for more detailed quantitative research. Future work in this area might include investigation of effective insulating materials and thicknesses for pipework, valves, flanges etc. However, routine thermographic measurement of this process produced on the shop floor requires a different approach.

The single most influential effect on accuracy is surface emissivity. For shop floor measurement, complexity of the objects being studied dictates that a common emissivity be used. For general measurements of lower temperatures, there is little effect on the final results between adopting an emissivity of 0.9 or 1.0. Consequently, a unit value is preferred for simplicity. Most industrial surfaces, being dirty and oxidised, will have an emissivity in this range. However, insulation cladding, some heat transfer surfaces, and galvanised skin casings of buildings and plant tend to have emissivities below 0.4; this severely affecting the results. These require initial identification.

For areas of low emissivity, it is necessary to make additional measurements and to select a suitable equation for quantitative interpretation of the isotherms. Equation - 4, given in Chapter VI and used for calculating temperatures in these experiments, was possibly unsuitable and a probable cause of some inaccuracy. A better equation would have been equation - 1. This however, required additional measurements, which added to the computation complexity and departed from the simple nature of the basic approach. In reality, therefore, qualitative measurement of low emissivity surfaces cannot be suitably produced from thermograms. This means that for most thermal distribution systems, whilst hot spots produced from poor lagging etc. can be identified (since like surface emissivities are being compared), actual evaluation of heat loss cannot be produced with any degree of accuracy.

This statement is further enforced by the adverse effects of weather variance on accuracy. The best results would most likely be derived from night surveys under constant weather conditions.

Laboratory simulation of heat lost in distribution might yield more promising results. It is apparent, for example that superheat in steam can be quickly lost within the system, and that the steam temperature often tends to relate to flow rate. Thermographic studies under controlled conditions would provide answers to optimum flows, degrees of superheat and lagging design.

The production of a global energy balance was a prime objective of the thermographic studies. Unfortunately, the results proved disappointing, with only a small portion of the heat dissipated from buildings being attributable to measured surface temperatures, the accuracy of which were also in question. Initially air-change was blamed for the unaccountable loss, but even with the relative uncertainty of the results, measurements indicated that with only a maximum of 25% of the heat lost in this way, a large portion was still being lost elsewhere. Speculation as to these losses include condensate to drain, steam leaks, drain water etc. The overriding conclusion, therefore, is that based on thermographic measurement alone, an energy balance and thus quantitative evaluation of the performance of energy usage cannot be made without additional measurement and increased complexity to the procedures.

One possibility, however, still exists and should become the content of future work. It may be possible to apportion energy usage to isotherm levels,assuming that these areas can be accurately defined and measured. Such hypothesis would need to assume that the rate of heat loss was proportional to temperature of the surface viewed,and that the rate would not alter with changing conditions of weather, water flow to drain, or air-change.

Chapter VIII reviewed the studies of single pieces of plant and equipment. To these, future work in the tyre industry might include studies of the heat developed in or the cooling rate of calendering and extrusion operations. Thermography may contribute much to the understanding of energy use in these processes. The point which needs to be emphasised, however, is that quantitative and sometimes qualitative analysis can be attributed higher degrees of reliability when confined to localised studies. Site surveys can at best produce little more than indications of where to carry out more detailed studies.

Thermography is still however, in its infancy. More recent developments have been made in the technology through improved portability of equipment, computerised computation of results, and compensation for abnormalities such as emissivity. With the high cost of the equipment, however,any departure from simple analytical procedure might pose questions against widespread adaption by industry on the grounds of energy conservation alone. As with many purchases, the justification for expenditure on equipment such as the A.G.A. 680 will only be made if thermographic techniques can be applied with advantage to not only the manufacturing equipment or buildings housing the operation, but also to development of the product itself.

CHAPTER X

THE RESEARCH REVIEWED

10.1 Chapter Preview

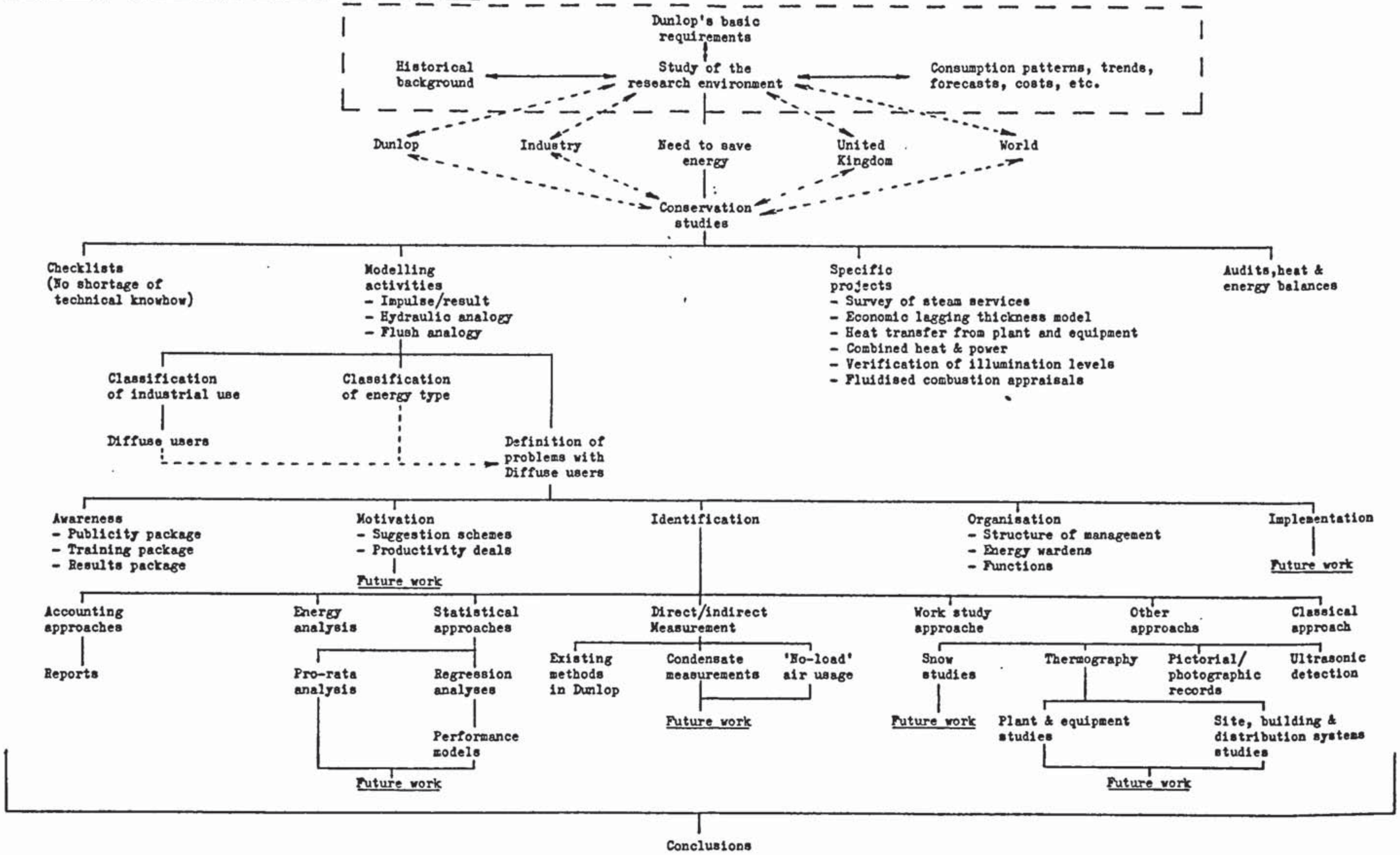
As with most concluding accounts, this chapter clarifies the overall progress of the research programme, recalling the comments summarised within the early chapters leading to the main objectives of the research activity. Discussion extends to the problems identified, not all of which were eventually provided with consequent solutions. Potential for future studies are, therefore, outlined.

Identification of poor energy performance is one of the most serious deficiencies facing diffuse users. Concluding remarks on the pros and cons of a number of possible techniques have already received much attention. All this chapter attempts is a consolidation of those views. Figure 10.2.1., summarises the flow lines of thought and progression of the research.

10.2 Progress of Research

Energy conservation techniques are for the most part well established and have been for a number of years - O. Lyle (6). There is no shortage of technical ideas. Resource shortages, higher costs and political pressures are compelling industry to use energy more effectively. These were but a few of the conclusions established from initial reviews of the Dunlop - National - International situation in 1974, and a

Figure 10.2.1 Flow Diagram of Progress Made During Research



comprehensive study of the available literature on conservation techniques.

Early investigations and feasibility studies of specific projects (321) (323), unfortunately omitted from this dissertation due to limitations on length of thesis, produced little reduction on consumption. With these means available, why then was there no impact? The first problem was to find the problems.

Modelling activities led to a number of analogies being drawn with energy consumption and conservation patterns. The initial product was the definition of the "Diffuse Industrial User". Here consumptions are widely distributed over a large area, often constituting small flows in a complex system not feasibly monitored by conventional means.

The first deficiency was judged to be awareness of energy usage, possible actions, and the need for improved efficiency. A publicity package, backed by a training scheme was implemented. These were specifically designed for the Dunlop operation and reflected a certain degree of success, mostly in the non-manufacturing areas. As with all programmes continuity is essential; to which end they are continuing.

Poor communication must be partially to blame for failure in the past in obtaining effective usage of energy. Reports and charts on monthly performance were circulated to the shop floor and management on a departmental basis. Routine cost-accounting communiques were rationalised to include pertinent data, and regular meetings held within the engineering function.

Awareness, without the necessary incentive, does not initiate action. Amongst senior managers, market force gave a suitable motivator, albeit that commitment was slow in coming. To promote improved housekeeping amongst all company personnel, a suggestion scheme was launched. At some later date it is hoped that this might include energy performance as part of a productivity deal.

Very critical to successful communication is the initiation of a formal organisational structure for energy management. Such a set up must have the commitment of senior management, be given the resources of time, money and manpower to carry out actions, and be handed the responsibility to maintain effective performance. Two engineers were appointed to this task, but with their activities being restricted to a consultative basis, having no control over the major issues or labour, full potential has yet to be realised. Every employee uses or controls energy in some form or other. Everyone should be their own 'Energy Manager'. What is required is a co-ordinator.

There are many functions to energy management. The engineering maintenance, technical and accounting disciplines have reflected some improvement. Purchasing electricity, water and fuel at the right price and under the right tariffs is a critical buying function. In the past a number of adverse contracts have resulted in financial loss to the company. Price trends, political actions and world events should be monitored and reflected in tariff negotiations.

The suggestion, as yet unintroduced, is the appointment of departmental wardens within the factory, office and transport functions. Such appointments would carry responsibility for good housekeeping and the importing of saving suggestions to the engineers.

Through the modelling activities, implementation of conservation actions was adjudged to be poor; some of the reasons for this were identified.

Energy price rises have resulted in increased "Energy Intensiveness", thus making this resource more important in company operations which, with increased management awareness, has effected partial improvement. However, the rate of implementation remains disappointing. Severe maintenance problems still exist. Improvement will only result from solution to the problems which must first be clearly defined:- a subject for further study.

Without due knowledge of where the inefficiencies lie, it is impossible to initiate improvement. Within diffuse industrial users, identification of energy use and misuse is poor. Although Dunlop biannual energy audits (96) have been and continue to be presented, the major difficulties still remained. It was this which formed the basis for the research.

10.3 Identifying the Inefficiency

The economic and general impracticality of monitoring every small energy flow in a complex, diffuse distribution system emphasised a need to establish alternative identification techniques. Since the initial recommendations made from early research, the Fort Dunlop system has undergone improvements. Departmental steam, space heating, air and water are now measured more accurately. Alterations to the distribution networks are being rationalised to give isolation of departments. Finally, automatic data gathering at some central point is being considered. Even with these, there are still many areas unmonitored, and it is still impossible to pinpoint losses directly from this data. Engineers may well make suitable use of some indicators, (i.e., a continuous steam exhaust from a pumping trap indicate passing traps) but a more rigorous approach to identification was required.

The studies began with a classical approach. By reviewing existing processes of energy conversion, it should be possible to ascertain the most effective system based on the theories of thermodynamics. With pre 1973 energy being cheap, operating costs were often less than initial capital expenses, the result being adoption of the cheaper less energy-efficient systems. By studying the existing plant, past projects etc., it is possible to identify points of improvement without leaving the drawing board.

This thinking was extended to the concepts of "Energy Analysis", from which inefficiency could be shown from investigations of the existing cost-accounting data through a systematic approach aspiring to the reintroduction of the energy balance. Linked to a quick walk-about the plant, problem areas can be assessed. It must be said that initial surveys might best benefit from the appointment of an employee, given the necessary time and co-operation, to carry out a visual inspection, and a few basic calculations based on simple measurement.

The need for a more rigorous analysis from existing data was paramount. It was clear that without identification of the factors controlling energy usage (production output, ambient temperature, etc.), useful analyses could not result. Regression techniques were successfully used to derive consumption models from which regular performance information could be derived. These models are presently being adopted in the energy-accounting system.

Having made an initial study of a department, the problems having been identified, it is then useful to establish the probability that the same things could be happening throughout the remainder of the site. Using statistical analysis, this was demonstrated by a pro-rata extrapolation of the number of passing steam traps found in one department.

Visual, audile and sensual perception of losses are constantly used to great effect by engineers. There can either be direct (i.e., a steam leak) or indirect (i.e., high oxygen content in flue gas = boiler inefficiency). Studies carried out using 'no-load' air consumption and condensate measurements to signify steam usage depicted their potential as identifiers.

The use of the senses can be used simply through direct sighting or in a compound analysis. The R.E.S.U.L.T.S., package was developed and tested as a technique for quantifying losses (i.e., heat loss from pipes by assessing the unlagged length). This method proved successful in establishing approximate values for early project evaluations. However, once linked to a training programme its potential becomes two-fold:

a. by actually noting the losses;

b. by making the participant more aware of energy misuse.

Associated with simple sighting is compound measurement of pressures, flows and other properties. Successfully used at Fort Dunlop for pin-pointing of passing steam traps was "Ultrasonic leak detection".

Thermographic techniques are an extension of visual identifications and must also be considered 'compound'. Potentially this method, with its inherent properties, offered a substantial answer to many problems. With a large portion of the research directed towards this end, a number of experiments were carried out, the objectives of which are given in table 10.3.1.

10.4 Potential for Future Studies

From the modelling activities discussed in Chapter II, it was shown that there was a positive delay between the impulse of some event to the completion of implemented actions. A number of possible reasons were given, such as - lack of awareness, insufficient employee incentive,

Table 10.3.1. Summary of Objectives for Thermography

1. To derive an alternative procedure for the identification of energy misuse in the 'diffuse' category of British Industry, traditional means being expensive, difficult to implement and time consuming.

2. To establish the feasibility and validity of thermographic remote sensing techniques for the qualitative, and subsequent quantitative determination of temperature 'hot spots' and hence heat loss from plant equipment, buildings, and entire factory sites.

3. To relate the determined losses to energy inputs (thermal, electrical or otherwise) entering the plant, equipment, building or site; thus establishing the feasibility of using thermography to obtain an energy balance.

4. To validate the hypothesis that energy loss could be identified and determined from successive stage 'focusing' or 'homing in' on the source, commencing at remote surveys of the site.

5. To establish the potential of thermography for detecting alterations, improvements or adverse changes in energy use brought about by conservation actions, production alterations or inefficiency.

6. To compile a library for future reference of thermographic records, showing the effects and behavioural patterns of heat loss and/or 'cold infiltration' with respect to plant and buildings.

management commitment etc. Some attempt was made at finding solutions to the problems, but of the six major areas, identification difficulties received the most attention. In reviewing the vista of unanswered queries, the whole aspect of sociological implications within energy conservation must provide fuel for future work.

Studies should be made of motivators and incentives, both from a shop floor and management viewpoint. What are the social, operational and political influences in implementing actions? Is the rate of response entirely dependent on variables such as annual turnover, profitability, company expansion etc? Researching such questions would encompass studies of a cross section of British Industry, would require a sociological as well as an engineering approach, and must be an important field for work. Within the confines of Dunlop and blessed with board commitments, a formal centralised communication link,perhaps made up of divisional members sitting in committee,would be the starting point.

Studies of identification techniques have already received much attention, but as an understanding and solving of the original problems emerges, further ideas are generated. Based on the statistical results, it is clear that investigations at departmental level will have to result before reliable models could be formed. At present only global site statistics have been used. Generally speaking a lot more data on plant operation needs to be gathered; for example:- statistical studies of standard equipment operation, involving the frequency of operation, age of plant, environmental conditinns, cycle times etc., with respect to rate of failure. Should trap or valve malfunction probability be assessed, planned maintenance procedures could then be implemented.

Again using the example of traps and valves, it may be possible to monitor critical properties, such as temperature, to assess their performance. A research programme for condition monitoring of plant and equipment is being established.

In steam main systems, the rate of heat loss is proportional to the condensate formed. A detailed study of Fort Dunlop mains was to be carried out with this research (349) (i.e., linked to thermographic results), but with the time limitations, remain in abeyance until some later date. Based on the thermographic studies of the Tyre 5 building, large quantities of heat were not accountable. It is proposed that future investigations be made of heat loss through condensate and cooling water systems. A further area to receive attention is the general layout of steam, air and water systems within Fort Dunlop. These are presently inaccurately charted and must be updated.

With water being a heat sink, perhaps critical temperature measurements in drains could show further loss. Investigation would have to be made of the entire drainage system before positioning of the thermometers could be established and this hypothesis verified.

Whilst it was demonstrated in the Tyre 5 survey that air change, extraction and ventilation were sources of loss, conclusive evidence of the total magnitude of this heat source throughout the site was not evaluated. A study of the ventilation procedures should be made, with possibilities of improvements and/or heat recovery discussed. Over the next twenty years, ventilation of industrial and commercial premises will dominate energy conservation activities, low grade heat recovery being of prime importance.

At the level of simple procedures, several unexplored possibilities remain. Observation of the domicile behaviourof birds, cats or 'rubber' insects might provide some light entertainment, but, whilst it is agreed that much energy goes to heat the sparrows, it is doubtful whether a full investigation will contribute to solution of the identification predicament. A more realistic study might be one of polarised - light variation on wet surfaces. The hypothesis presupposes that the degree of wetness will vary with the heat conducted through the surface, and that only wet areas will reflect polarised light. Chapter VII discusses this in greater detail.

Such a procedure represents an indication of loss from say a roof-top. It might also be conceded that a paint with colour/temperature variance be painted on the roof. Alternatively this could be put on pipework (i.e., down-stream condensate lines), thus indicating abnormal operating conditions. Such potential needs to be evaluated. The effectiveness of this method is already clear to gas-turbine manufacturers. At a lower temperature level and in a non-technological environment, the reliability is less certain.

10.5 A Package for 'Diffuse' Industrial Energy Users

Including probability statistics, pro-rata extrapolation of known inefficiencies may be an improvement on pure guesswork but gives little more than a feel for the magnitude of global loss. It is difficult to ascertain accurate information to begin with, but assuming this to be representative, the technique can be usefully deployed in general appraisals for management plans and forecasts.

With respect to performance monitoring, present methods of budget control encompass measurements based on the weight of tyres produced. This fails to account for effects of ambient temperature or energy overhead. The models derived in Chapter V must provide a better system.

There are, however, associated problems with the technique. Marginal consumption cannot be distinguished from variable overheads, and whilst the gradient of a line is assumed to reflect reliability, no such accuracy can be attributed to fixed overhead. Subdivision of consumption patterns into those theoretical categories given in Chapter V cannot be realised. It is, therefore, difficult to classify conservation actions in this way.

Generally speaking, only large alterations to Fort Dunlop consumptions (i.e., substitution of gas/oil for coal) can be identified. Without individual departmental analysis, smaller changes will tend to be offset by counter effects and lost in the overall site pattern. Similarly it is dangerous to presuppose that interfactory comparisons can be made on this basis. Each site will produce anomalies resultant from varying properties such as plant and building age, operating conditions and product mix. It is doubtful that a global model would carry any credibility.

Remote sensing of heat loss from buildings may be a suitable starting point for factory energy analysis, the aim being that through successive investigations the actual point of loss can be defined. The simple technique of observing snow melt on rooftops and roadways has proved successful within certain limitations. The three modes of heat transfer can be readily identified. The technique is simple and quick to apply and is much cheaper than thermographic methods. However, only qualitative analysis is possible, with success relying on the correct snowfall. Finally, no losses can be pinpointed inside the buildings.

Thermography overcomes some of these deficiences and in theory, extends to quantitative analysis of losses. The results of this research have demonstrated that rapid surveys of sites can be made from remote positions. With few exceptions, qualitative information on energy usage patterns may be determined, for varying 'boundary' sizes, from whole sites to specific plant and equipment. The process can be used for improving maintenance/housekeeping; establish effective insulation standards; discover flows and non-homogeneity in joints (welds) and materials; improve production control with reduction of scrap; aid technical development and quality control; and lastly provide a simple way of comparing plant to establish efficiencies.

Quantitative analysis within the 'real' industrial environment, outside laboratory conditions, departs from the rudiments of simplicity. Apart from complexity in computation of the results, an accurate reference source is required. Similarly, the objects being viewed must not significantly depart from the black-body ideal. Quantitative, or even qualitative measurements of low emissivity surfaces are difficult and for the most part inviable. This makes studies of thermal distribution systems unrealistic due to the aluminium cladding.

With one objective being to establish site and building energy balances, the results show that due to inaccurate reference temperatures, multi-emissivity surfaces, convective discharges, and unaccountable losses, the thermographic technique is limited. Many additional measurements are still required.

It is also clear that, for the engineer using the equipment, knowledge of the objects being viewed is essential. Correct operation of the equipment plus interpretation of the results requires skill not readily available outside technological research and development. Further associated problems are summarised in Table 10.3.1.

The conclusions drawn in Chapter VIII and IX point to the need for further study. Under simulated laboratory conditions, further investigation might establish effective insulation standards and economic lagging

Table 10.5.1. Thermographic Techniques - Summary of Disadvantages

1. Effects of emissivity.
2. Effects of attenuation.
3. Reflection effects for low emissivity surfaces.
4. Complexity in operation of equipment.
5. Complexity in computation of thermograms for quantitative measurement.
6. Difficulties in assessing object dimensions.
7. Transparent material effects.
8. Hot gases and convective losses are not easily measured without spectral filters.
9. Resolution and photographic quality.
10. Effects of view factor (i.e., reflected radiation).
11. Additional measurements often required particularly for aerial or remote sensing.
12. High cost of equipment.

thicknesses for thermal tanks and distribution systems. There is a need to have better understanding of heat losses in steam networks. For example, what is the real rate of loss of superheat in the Fort Dunlop system? Is superheat needed from the boilers to give dry-saturated steam at a press-line. With the pressure having undergone successive reductions from that of generation at 21 bar, superheat could be added at each stage.

If it were assumed that all surfaces were black bodies, or that emissivities were > 0.9, continuous colour monitors (156) could be used to monitor the site, buildings or plant. This would provide the means for constant, real-time perusal of performance. Associated with computerised comparison facilities, identification of inefficiency is instantaneous.

Although the production of energy balances may not be attained directly from thermograms, it may be possible to hypothesise that site heat losses are proportional to the temperature distribution on the roof-tops. If the energy inputs were known, the losses could be apportioned on same statistical basis. This must be a study for a future research programme.

Whilst many problems exist, associated with additional measurements the use of standard thermography holds great potential for quick identification of inefficiency. An energy engineer conversant with the interpretation of the thermograms and objects being viewed can inspect quantities of plant, equipment and buildings from remote positions in a short period of time. The procedure might well be dubbed - "Homing in on Hot Spots". Albeit that quantitative measurement is not always simple, the technique must contribute to identifying performance inefficiency.

Judged from these studies, it is unlikely that any single procedure could ever provide all the answers to the identification predicament. With each 'diffuse' plant having different physical properties and operating under varying constraints, the solution will most probably be in adoption of a combination of the afore mentioned techniques. Perhaps in the present industrial climate, highly sophisticated metering might succumb to the simplicity of identifying losses as a consequence of committing an employee (with some prior engineering knowledge and site experience, and with the resources of time, finance and manpower) to walk the site and note the inefficiencies. To this aim, thermography might contribute a greater understanding of consumption patterns.

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