A HEAT METERING SYSTEM FOR ENERGY MANAGEMENT ON AN INDUSTRIAL SITE

A thesis submitted by:-

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to the University of Aston in Birmingham

for the degree of Doctor of Philosophy

May 1985

The University of Aston in Birmingham

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Summary

Faced with a future of rising energy costs there is a need for industry to manage energy more carefully in order to meet its economic objectives. A problem besetting the growth of energy conservation in the UK is that a large proportion of energy consumption is used in a low intensive manner in organisations where the would be responsibility for energy efficiency is spread over a large number of personnel who each see only small energy costs.

In relation to this problem in the non energy intensive industrial sector, an application of an energy management technique known as monitoring and targetting (M & T) has been installed at the Whetstone site of the General Electric Company Limited in an attempt to prove it as a means for motivating line management and personnel to save energy. The objective energy saving for which the M & T was devised is very specific. During early energy conservation work at the site there had been a change from continuous to intermittent heating but the maintenance of the strategy was receiving a poor level of commitment from line management and performance was some 5% - 10% less than expected.

The M & T is concerned therefore with heat for space heating for which a heat metering system was required. Metering of the site high pressure hot water system posed technical difficulties and expenditure was also limited. This led to an 'in-house' design being installed for a price less than the commercial equivalent.

The timespan of work to achieve an operational heat metering system was 3 years which meant that energy saving results from the scheme were not observed during the study.

If successful the replication potential is the larger non energy intensive sites from which some 30 PJ savings could be expected in the UK.

Keywords: Industrial energy management; Monitoring and Targetting; Heat metering.

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ACKNOWLEDGEMENTS

I would like to acknowledge the help and facilities provided by the University of Aston in Birmingham and my sponsor GEC Gas Turbines Limited of Whetstone near Leicester.

I am grateful to Dr. G. Beaumont of the Department of Production Technology and Production Management at the University who was Main Supervisor of my work. I would like to express my appreciation to Mr. D. C. Hickson for making the initial arrangements to study under the Interdisciplinary High Degrees Scheme (IHD) and for subsequently acting as my IHD Tutor.

The staff at GEC Whetstone who I would particularly like to thank for their support are: Mr. M. G. Payne, Estates Manager; Mr. H. H. Taylor, Manager, Plant and Buildings Department; Mr. M. W. Nash, Heating and Ventilating Engineer; Mr. R. Grant, Works Electrical Engineer; and Mr. D. H. Jarvis, Boiler House Foreman. Special thanks must go to Mr. G. A. Knighton, Senior Maintenance Engineer, who acted as my Industrial Supervisor.

CHAPTER 1

INTRODUCTION

1.1 Energy

Energy is an essential input to our modern industrial economy. It is by the expenditure of the various energy resources that industrial systems are able to win all raw materials and turn them into products and services for the benefit of society. For the best part of the last 200 years energy has been in plentiful supply from fossil sources at low and sometimes even decreasing costs and has essentially fuelled increasing industrialisation, raised standards of living and supported a growing population.

Unfortunately, such have been the demands of economic growth that fossil fuel reserves are becoming depleted. There is a growing awareness based on numerous forecasts of economic growth and estimates of world reserves that energy consumption commensurate with the forecasts cannot be sustained much beyond the end of the century. A review of various official forecasts is used by the Department of Energy in its Green Paper on Energy Policy in 1978, (1). Table (1.1) extracted from this document shows that with a 4% exponential growth rate ultimate reserves of oil are estimated to last for 37 years (from 1975), gas for 51 years and coal between 71 and 110 years. A 4% exponential growth with energy demand increasing at a roughly similar rate is by no means unexpected because of third world development, (2) and (3).

If therefore there is to be a growth in energy demand it must be met either by the discovery of new sources of fossil fuel or by the development of nuclear power and renewable resources like solar, wind, wave, tidal and geothermal power. The small likelihood of any of these programmes except nuclear power making a major contribution to world energy supply before the year 2000 is acknowledged by most western consumer governments, (1).

Historically, the growth in energy demand since the Second World War has been met by increasing use of oil and natural gas as shown in Fig. (1.1). The economies of many industrialised countries are now so heavily dependent on these fuels that this dependency cannot be changed quickly without severe social and economic consequences. The oil crisis of 1973 has demonstrated that OPEC (Organisation of Petroleum Exporting Countries) can exert massive economic and political powers over the supply and pricing of oil and their position as major suppliers to the international market has, somehow, to be moderated, (1).

1.2 Energy Conservation

Faced with these somewhat alarming prospects, a number of alternative energy stategies are being examined by most industrialised countries. For the United Kingdom, the Department of Energy, (1), proposes a strategy based on the development of coal, nuclear power and energy conservation in order to satisfy needs onwards from the mid-1990s when North Sea oil and gas production move into decline.

Wherever it is possible for energy conservation to substitute for another energy source there are a number of advantages. The Advisory Council on Energy Conservation appointed by the Government through the Secretary of State for Energy believes in the importance of the following factors, (4):

- cost-effective energy saving measures will make industry, and indeed the country, more efficient, competitive and profitable, and better equipped to win and hold markets, so helping the balance of payments;
- by reducing pressures on energy supplies, particularly oil dependency among OCED countries (Organisation for Economic Co-operation and Development), more efficient use of energy is likely to strengthen the chance to contain energy prices world-wide. It will also help economic growth, prolong UK energy self-sufficiency, and decrease vulnerability to future shortages;
- by contributing to the avoidance of future energy shortages and the associated upward pressures on prices, wise use of energy by the developed nations will assist the developing nations, many of whom are heavily dependent on energy imports (and

especially oil); their economic growth is of benefit not only to them, but to the developed nations as well;

- in many cases energy efficiency measures can be introduced without the environmental controversy that often surrounds new supply projects. The impact of energy supply activities can no longer be considered small and the external costs of supply are coming under ever-increasing scrutiny;

- in relative terms, for a given quantity of energy, the costs of improving energy efficiency are often less than the costs of supply; many energy efficiency investments offer distinct benefits in terms of their high returns, short lead times and low technical and commercial risks;

- energy efficiency measures in the home can lead to better comfort levels and hence increase standards of living;

- energy efficiency measures in buildings, by reducing the quantity of energy consumed, widen and sustain the opportunities to consumers for fuel and appliance choice;

- energy efficiency measures sill provide spin-off benefits on employment, not only through stimulating the provision of energy saving equipment and services, but also by increasing the competitiveness of the nation.

Although now a part of long term strategy, energy conservation is an activity which developed hurriedly in response to the disruption of the world economy following the oil crisis in 1973. The economy had to adjust to a step change to higher energy prices. Inevitably the increased prices were passed onto the consumer who became increasingly hard pressed to pay. This resulted in a depressed world economy, (1). Energy conservation on the other hand offered scope for reducing the severity of price increases.

In the ten years since the oil crisis many consumers have sought to reduce costs through energy conservation. Equally there are those who have not taken up opportunities for energy conservation and there are those who have met with only limited success. The Advisory Council on Energy Conservation has identified a number of barriers to energy conservation, (4), and these are shown in Table (1.2).

1.3 Energy Management

In view of the increasingly complex factors affecting energy supply and the potential for energy conservation there is the need to change consumer attitude from one of simply buying whatever fuels are required to one where energy management is practised.

From the consumer viewpoint, the objective of energy management is to achieve a reduced 'total' cost for energy relative to productivity based on a combination of bought-in energy and investment in beneficial conservation measures. Chapter 2 of this thesis contains a state-of-the-art review of the development in techniques and practise of energy management.

1.4 Progress with the introduction of Energy Management

The Department of Energy has monitored progress with the introduction of energy management, (4). They report that progress is slow except in the energy intensive industrial sector.

As shown in Table (1.3), the energy intensive industries consumed only 16% of gross UK energy consumption in 1983. For these industries, the driving force to conserve has been that energy input makes up a large part of the manufacturing value added.

The other consumers, that is the energy non-intensive industries, transport, domestic and commercial sectors account for the remaining 84% of gross energy consumption in the UK, as shown in Table (1.3). Clearly, the possibilities of practising energy management in these sectors needs to be studied. In contrast to the energy intensive industries all these sectors use energy at low intensity and are generally less well organised for management of energy in that there are large numbers of people responsible for energy use with each seeing an energy cost which to himself is small or even insignificant compared to other operating costs. It is in these sectors where the barriers to energy conservation put forward in Section 1.2 and Table (1.2) prevail.

Use of energy in non-energy intensive sectors is predominately in the space conditioning and services in buildings. Some 40 - 50% of gross UK energy supply is destined for use in buildings, (4), accounting for 40% of industrial sector consumption and virtually 100% of the consumption in the domestic, public and commercial sectors. Energy conservation measures for buildings are therefore an interesting category because of the replication energy saving potential throughout the whole of the building stock.

1.5 Project Framework

This brief introduction demonstrates firstly that there is a need to conserve energy but secondly that 84% of gross energy consumption in the UK is amongst a large number of users who are dispersed and have, as is shown in Table 1.2 little knowledge or incentive to conserve energy. If there is to be a growth in energy conservation in the UK then energy management must be developed for the non-energy intensive sectors.

Developments in management technique, in whatever department, must be proven against the real world in order that they gain a proper standing and for this reason it is best that developments in energy management are made with reference to an actual situation rather than a hypothetical one. The contribution of the work described in this thesis is a development in energy management aimed at overcoming some particular barriers to energy conservation at one typical non-energy intensive industrial site within the GEC Group of Companies (General Electric Company Limited).

1.6 GEC Whetstone

1.6.1 The Site

GEC Whetstone is a 53 acre industrial estate near Leicester which is operated by GEC to provide office and factory accommodation for its subsidiary companies. During the period 1979 to 1984 which covers the undertaking of the work described in this thesis, six tenant subsidiaries occupied the site and were involved in a variety of activities as follows:

GEC Gas Turbines Limited (GTL)

Business:	Supply of gas turbine drives for electrical power generation and for pumping duties on gas and oil pipelines.
Site activities:	Office accommodoation for sales, design, purchasing, personnel and accounts functions. Factory accommodation for machining of turbine blades and rotors, assembly and testing.

GEC Energy Systems Limited (ESL)

Business:	Supply of components for nuclear reactors and for new energy technologies, for example,. heat pumps.

Site activities:	Office accommodation for sales, design, purchasing, personnel and accounts functions. Factory accommodation for assembly.

GEC Mechanical Engineering Laboratory (MEL)

Business:	Applied research in support of GEC business and consultancy to industry and Government.
Site activities:	Office accommodation, laboratories and test rigs.

GEC Central Metallurgical Laboratory (CML)

Business:	Monitoring of materials in service in GEC products, particularly metal creep in turbine blades.
Site activities:	Office accommodation and laboratories.

GEC Midland Computer Services (MCS)

Business:	Computer time for GEC and other clients.
Site activities:	Computer room.

National Nuclear Corporation (NNC)

Business: Design and construction of nuclear power plant.

Site activities: Office accommodation for design and project management. Laboratories and test rigs for equipment appraisal.

A plan of the site is shown in Fig. (1.2). Total office accommodation amounts to 27000 m^2 floor area, factory space to 33000 m^2 and laboraties/test rigs to 16000 m^2.

The tenant subsidiaries are provided with the use of central site facilities which include telephones, canteen, cleaning, maintenance and power utilities namely heat, electricity and compressed air.

Heat

Heat is distributed via high pressure hot water (HPHW) mains shown in Fig. (1.3) and is served from the central boiler house having some 23 MW(t) of capacity.

Electricity

Electricity is distributed from a high voltage ring main via on-site sub-stations as shown in Fig. (1.4). Supply capacity purchased from the East Midlands Electricity Board is nominally 4.2 MW(e).

Compressed Air

The compressed air system which serves the factory areas and laboratories/test rigs is shown in Fig. (1.5). Compressors are operated at 1 bar and have a free air delivery rating of 2750 L/s.

The Estates Division undertakes to provide the site services to the various tenant subsidiaries. The Division is headed by the Estates Manager who reports to GEC board director level.

1.6.2 Energy costs in relation to other costs

Energy costs for GEC Whetstone during April 1979 to March 1980 are shown in Table (1.4). Total consumption of natural gas, heavy fuel oil, gas oil and electricity amounted to 246000 GJ valued in 1979/80 at £740620.

It is difficult to obtain other costs from GEC accounts to compare against energy costs. Operating costs in any company are guarded commercial secrets and not divulged to anyone except those who need to know to run the company. Furthermore, in the GEC Group of Companies, the published trading position of each subsidiary is disguised by aggregating accounts. In law, GEC subsidiaries like GTL and ESL are agents acting on behalf of a holding company. All payments are made to and from accounts belonging to the holding company and consequently the agent does not submit a profit/loss account to the Department of Trade and Industry at Companies House, London. The balance sheet which is submitted, contains minimal information except to show that GTL and ESL are £100 companies with £99 of the shares issued being owned by the holding company and £1 owned by the resident managing director, (7) and (8).

NNC is the third major presence on the Whetstone site. NNC is owned by a consortium in which GEC has a 30% share. NNC has to publish full accounts. Until 1980, NNC was two companies namely Nuclear Power Corporation (Whetstone) (NPC(W)) and Nuclear Power Corporation (Risley).

The accounts for NPC(W) are of interest and for year ending 31 March 1980, (9), show turnover as £97M with profit before taxation of £1.2M. Unfortunately these are meaningless in the context of energy cost comparisons. The £97M turnover was due to a large involvement in contracting work at nuclear power station construction sites. The construction sites incurred energy consumption, the cost of which appears in the contractor's fees and is totally divorced from the Whetstone site energy bill as far as any single person is concerned. The profit figure is likewise meaningless except to show that it is of the same order as the energy bill for the whole of the Whetstone site, that is £1.2M profit and £0.74M site energy cost (in 1979/80).

Faced with this lack of financial information it was necessary to examine site functions more closely to generate estimate costs for comparison with the energy cost.

It is important when assessing the energy intensity of a site to compare the energy cost against 'value added due to site activities'. Raw material costs do not appear in the analysis since on an input-output basis these costs are merely summed with the value added to become the sale value of the product.

On the Whetstone site, added value is due mainly to human labour. The site is labour intensive. As stated in Section 1.6.1 there is 27000 m^2 of office accommodation which is 36% of total building floor area. Approximately 3000 personnel out of a total workforce of 4000 are employed is these areas. It is presumed that wages and salaries are the predominant cost element in office based activities.

Furthermore, labour cost in manufacturing at Whetstone is likely to be the biggest cost element. The 33000 m^2

of factory floor area (43% of total floor area) is used as follows:

	Area	% of Factory Area
Machine tool shops	16700	51
Heavy fabrication including ferrous welding	3300	10
Light fabrication including sheet metal working, electrical and turbine assembly	7600	23
Stores	5400	16
	33000	100

Fabrication processes are labour intensive and require relatively low cost tools. Only in the machine tool shops will the cost of providing the machine tools themselves be significant. Stores areas are generally low cost.

The Laboratory and Test Rig areas at Whetstone which cover 16000 m^2 (21% of total site area) have only small costs associated with them which are covered in the overheads of office based activities.

In a labour intensive environment like GEC Whetstone, costing is based on basic labour rates to which a overhead charge rate is added to give the 'charge out' rate. Total charged out work per annum is equivalent to 'value added' per annum. Overhead rates vary depending on worker skill, his workplace and the tools he uses. The following are ranges of overhead rates applied at GEC Whetstone.

	Range of overhead rates
Office staff	100 - 400%
Site labourer	100 - 150%
Fabricator	100 - 200%
Machine tool operator	700 - 1600%

Taking the average gross wage on the site in 1979/80 to be £7000 it is estimated that value added in that year was between £70M and £110M.

The validity of these figures can be 'weighed-up' against some snippets of information that have been published, as shown in Table (1.5).

With added value at between £70M and £110M, the £740620 energy bill represents only ½% to 1%. This is commensurate with a non-energy intensive industrial site, (15).

1.6.3. Site Energy Conservation Programme

The progress of energy conservation work at GEC Whetstone is documented in a PhD thesis by Rodrigues, (16), who undertook research to support the programme of energy conservation work at the site. His research work was undertaken during the period 1976 until 1980 under a collaborative arrangement between GEC and the University of Aston in Birmingham, Interdisciplinary High Degrees Scheme, Total Technology Option. It is worthwhile at this stage to mention that the author's work was carried out under a similar arrangement and followed-on from the work by Rodrigues.

The organisational initiative for an energy conservation campaign in GEC stemmed from the creation in 1974 of a Corporate Energy Adviser (CEA) reporting directly to the Managing Director of GEC Limited. With the numerous and diverse sites within GEC it would have been an arduous task to establish and maintain an effective organisational structure reporting, say, directly to the CEA.

To keep the communication hierarchy simple, responsibility for energy conservation was vested in the Estates Division at each site. Each site therefore co-ordinates its own energy conservation programme with funds being found from the Estates Division budget. Scrutiny of the effort on each site is monitored by the CEA at intervals of 2 to 3 years by way of an audit lasting 3 to 5 days.

At GEC Whetstone, Rodrigues reported on both his own and the CEA's analysis for the site. He concludes that when taking 1972/73 as the base year, and after taking into account weather and different levels of production, then consumption is on average 13% lower in recent years due to energy conservation measures implemented during the period 1974 to 1979.

Rodrigues further concludes that future energy conservation work on the site is limited. For the on-going energy conservation programme he prescribes work in the following fields:

(1) Waste heat recovery

(2) Improvements to the intermittent heating strategy for the site

One of the energy conservation measures already implemented on the site was the elimination of continuous space heating in buildings by the installation of remotely controlled motorised valves in all heating circuits. Rodrigues monitored the energy saving performance of intermittent against continuous heating and whilst doing so observed a number of 'site problems' (Rodrigues, (16), section 5.3.7).

(3) Alternative methods of supplying domestic hot water in the Summer months

The present use of the central boiler plant and HPHW distribution mains on a low load factor supplying must hot water service results in low system efficiency.

1.7 The Project

The author's work was an integral part of the established and on-going energy conservation programme at GEC Whetstone which commenced in 1974/75. The work to be described in this thesis is a contribution to a three stage energy savings plan for the site, these three stages being:

STAGE 1 - the implementation of 'good housekeeping' measures.

STAGE 2 - the extension of Stage 1 to include measures requiring greater technical and capital resources.

STAGE 3 - the inclusion of energy efficiency considerations in the longer term development of the site.

Recognising that further energy reductions after Stage 1 would become increasingly difficult to achieve, the Estates

Manager undertook to support a programme of research and specialist project work aimed at examination and implementation of measures in specific areas of Stages 2 and 3 of the plan. The necessary expertise was acquired under a collaborative arrangement with the University of Aston, Interdisciplinary Higher Degrees (IHD) Scheme, Total Technology (TT) option.

The IHD Scheme at Aston University aims to place students in industrial organisations to undertake research and project work in agreed problem-areas. For the collaborating industrial organisation, there is the prospect of progress towards solving the problem, for the student there is the opportunity to submit a write-up of his work for a higher degree and for the University there are the advantages of being directly informed about industrial practice of today. Supervision of the work is provided by senior personnel from both the university and the industrial organisation.

At GEC Whetstone, Rodrigues was employed during the period 1976 to 1979 as has been previously mentioned. His thesis (16), reports on the comprehensive energy conservation measures undertaken on the site. The author reviews Rodrigues' work and that of others in the energy conservation field in Chapter 2.

The author's employment at GEC Whetstone during the period 1979 to 1982 under the same collaborative arrangement between GEC and IHD as Rodrigues was to continue the specialist input to the site energy conservation programme. Clearly, from the GEC viewpoint, the author was expected to look at the areas of further work as directed by Rodrigues and which have been outlined in Section 1.6.3.

Rodrigues gave estimates of the potential economic energy savings for each area of further work on the site.

(1) Waste heat recovery

Several waste heat recovery applications exist on the site but are not economically exploitable. These, however, should be kept under review as energy costs rise and waste heat recovery technologies develop.

(2) Improvements to the intermittent heating strategy for the site

Rodrigues made two estimations and one further theoretical calculation of the savings due to intermittent heating. The first estimation was based on comparison between the last year during which continuous heating was practised and the first year following the commissioning of intermittent heating. A 10 - 20% saving was shown.

The second assessment was based upon monitored data taken in four buildings during week long periods of continuous heating followed by a week of intermittent heating. From the weekly data, Rodrigues calculated the following savings for intermittent heating.

Block 52C: Temporary office block
occupied 0830 - 1700 - 27% saving

Block 51 : Permanent office block
occupied 0830 - 1700 - 50% saving

Block 2 : Machine shop
occupied 0730 - 1615 - 21% saving

Block 75: High bay fabrication shop
occupied for 2 shifts
0730 - 1615 and
2100 - 0730 following day - 12% saving

Based on these figures, Rodrigues suggested that annual savings due to intermittent heating should be some 10 - 30% in office and laboratory areas and 10 - 15% in factory areas. Whilst undertaking monitoring he observed how seemingly trivial acts on the part of personnel in buildings made it difficult to operate intermittent heating. For example, leaving windows open overnight or covering radiators meant that the required internal temperature could not be attained at the start of occupancy. This in turn led to requests for return to continuous heating, or requests for portable bottle gas heaters, or the use of electric fan heaters to overcome the 'problem'. Rodrigues saw that, in order to achieve the full savings for intermittent heating, this behaviour had to be stopped by changing the attitudes of personnel in buildings best achieved through a firm commitment of management at all levels.

The benefits of properly involving personnel is approximately the 5 - 10% difference in savings indicated between the two assessments made by Rodrigues. The first assessment of 10 - 20% based on comparison of annual fuel consumptions includes the effects of operating difficulties. During monitoring for the second estimate there was a close watch on the buildings to ensure that the test case was maintained and therefore problem-effects were largely eliminated.

The theoretical calculation by Rodrigues saving due to intermittent heating showed potential savings varying from 41% in lightweight buildings to 14% in ones with heavyweight structure. He points out that these figures are comparable with work by others such as Bloomfield et al (17) whose methods yield 34% and 14% saving in the same respective cases.

Based on Rodrigues estimation of space heating consumption on the Whetstone site and the associated boiler plant and distribution losses, the 5 - 10% saving from properly involving personnel in conscious-minded energy use is calculated as follows:

Fuel consumption attributable to space heating:

From Rodrigues (16):

Use	% total consumption
Space heating	60.5%
Boiler losses	23.4%
Distribution losses	11.6%
Domestic hot water	3.7%
Process heat	0.8%
	100.0%

Total useful heat = 65%

Total losses = 35%

Space heating apportioned losses = $\frac{60.5}{65} \times 35 = 32.6\%$

Total consumption attributed to space heating

= 65 + 32.6 = 97.6%

In view of the large tolerances on other estimated figures, this is approximated to 100% of natural gas and heavy fuel oil being used for space heating. From Table (1.4) this amounted to 166100 GJ valued at £276440 in 1979/80.

Returns from a 5 - 10% heat saving:

The saving is fuel consumption and costs from achieving a 5 - 10% saving by properly involving site personnel in conscious-minded energy use is therefore 5% and 10% of the above figures, that is an energy saving of between 8300 GJ and 16600 GJ per annum valued at approximately £13800 and £27600 respectively at 1979/80 prices.

(3) <u>Alternative methods of supplying domestic hot water in the Summer months</u>

According to the energy audit carried out by Rodrigues, 2050 GJ per annum of fuel are used during the Summer months to provide 330 GJ input to domestic hot water service and 80 GJ to process heating. The combined boiler and distribution efficiency is only 20% The 80% waste is 34% boiler losses plus 46% heat dissipation from distribution mains. If these could be reduced or eliminated by alternative means of supplying the heat the potential maximum saving would therefore be 80% of

2050 GJ equal to 1640 GJ per annum. At 1979/80 prices this would have been valued at £2690.

One alternative method of supplying Summer hot water service is solar assisted heating. This is currently being investigated for the Whetstone site by MEL with EEC funding.

Based on Rodrigues work therefore the most beneficial area in which to work was to make improvements to the intermittent heating strategy for the site. As has been stated, the savings potential in this area is between £13800 and £27600 per annum at 1979/80 prices. These figures are far more substantial than the £2690 per annum saving estimated for alternative methods of supplying domestic hot water in the Summer months and for waste heat recovery where in 1979/80, according to Rodrigues, no applications were economically exploitable.

The problems with intermittent heating at GEC Whetstone which were observed by Rodrigues were of two types, as previously stated in section 1.6.3, namely 'site' and 'organisation' problems. The site problems were basically of an engineering nature such as the lack of boiler and heating plant capacity to meet start-up loads. These problems were rectified before Rodrigues completed his work in 1979. (Rodrigues, (16), Section 5.5). The so called organisational problems were where the author started his work.

The organisational problems observed by Rodrigues described earlier in this section are symptomatic of some of the barriers to energy conservation referred to in Section 1.2 and shown in Table (1.2). It has been shown in this introduction that at GEC Whetstone fhe following barriers specifically exist:

(1) Institutional problems especially in tenant/landlord arrangements.

(2) Highly disaggregated nature of energy consumers in buildings and the need for them to play a positive role.

(3) Relatively small cost of energy in total costs.

(4) Lack of management expertise and poor management attitudes (on the part of line management).

(5) Lack of knowledge (on the part of line management).

(6) Traditional conservatism and inertia (on the part of line management).

(7) Lack of poor operational control including lack of measuring, monitoring and targetting.

This final item gives mention to an important tool for bringing management and staff into line with corporate objectives for energy efficiency. Measuring, monitoring and targetting is essentially management accounting for the use of energy. Through the use of metering and costing energy supplies to a given area against an agreed budget, line management can be made responsible for energy use and energy efficiency. Under such an arrangement there is the incentive for a manager to consciously adopt a rational attitude towards energy use and to acquire whatever knowledge is required to run his department energy-efficiently.

Unfortunately, at GEC Whetstone it is neither easy nor cheap to provide each manager with his own metered energy consumption, especially the heat consumptions that are required for monitoring and targetting at line management levels to motivate their co-operation in maintaining the effectiveness of the intermittent heating strategy. This is because there are numerous managers and heat to each one is rarely supplied conveniently from a source which is clearly definable as his supply.

The author's contribution was to generate heat metering consumption information for line management use at an acceptable cost in order that operational control through monitoring and targetting could be exercised. The primary purpose was to establish and maintain additional savings from the intermittent heating strategy for the site. The aim was to achieve a 5 - 10% saving on space heating consumption which had been shown to be possible from the work carried out by Rodrigues.

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1.8 Appraisal of investment in heat metering for monitoring and targetting

In justifying capital expenditure on energy conservation projects, GEC used the simple payback formula with annual fiscal return equal to the value of the fuel saving in the year capital expenditure was made. This simple approach was somewhat justified because it offsets to a degree the predictions of future increases in the relative price of energy against the discounting factor which would be present in more sophisticated calculations such as discounted cash flow methods.

GEC criteria for payback was 5 years.

In Section 1.7, the objective of savings in space heating consumption of between 5% and 10% were valued at £13800 and £27600 respectively, 1979/80 prices. Based on the minimum of the range the capital expenditure which could be justified in 1979/80 was 5 x £13800 = £69000. The costs of heat metering for monitoring and targetting had to be within this amount.

1.9 The Thesis

Later chapters in this thesis describe the author's work to devise a heat metering system providing information to managers about space heating consumption monitoring and targetting in the buildings they occupy. In its simplest overall terms the work was to study:

(a) The feasibility of providing a heat metering system performing the above function on the GEC Whetstone site for a cost of less than £69000 (in 1979/80).

(b) The anticipated savings on space heating consumption from monitoring and targetting with the system were in fact between 5 and 10%.

(c) The implications of the work to other energy users.

However, it is clear that the staging point and validity of the author's work is heavily dependent on the correctness of the conclusions and recommendations for further work given by Rodrigues. The next chapter is therefore a review of the work by Rodrigues and others in the energy management field.

Table (1.1) : TOTAL WORLD FOSSIL FUEL RESERVES AND CONSUMPTION

Source : Department of Energy, (1)

Table (1.2) : BARRIERS TO ENERGY CONSERVATION

Source : Department of Energy, (4)

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Table (1.2) continued : BARRIERS TO ENERGY CONSERVATION

Source : Department of Energy, (4)

Table (1.3) : INTENSIVE AND NON-INTENSIVE ENERGY USE IN THE UK DURING 1984

Source : Department of Energy, (5)

Fuel	Main uses	Units	GJ	Cost (£)
Natural gas	Space heating Hot water service	1 477 630 therms	155 900	256 180
Heavy fuel oil	Dual fuel standby to natural gas	248 780 litres	10 200	20 260
Electricity	Lighting H & V and AC* Machine tools Process heat Compressed air Turbine testing Laboratories Space heating	15 889 000 kWh	57 200	375 380
Gas oil	Turbine testing	595 800 litres	22 700	88 800
Totals			246 000	740 620

* H & V and AC - Heating, ventilating and air conditioning : Pumps, fans and chillers.

Table (1.4) : ENERGY SUPPLY AND COSTS TO THE GEC WHETSTONE SITE APRIL 1979 TO MARCH 1980

- GEC Power Engineering Limited

  Turnover for 8 sites including Whetstone in years (April - March) :

1974 / 75	-	£M 192
1975 / 76	-	£M 251
1976 / 77	-	£M 306
1977 / 78	-	£M 393
1978 / 79	-	£M 401
1979 / 80	-	£M 427
1980 / 81	-	£M 531
1981 / 82	-	£M 589

  Sources : (10), (11), (12) & (13)

- GEC Gas Turbines Limited

  Order book for April 1978 to March 1979 was £M 55 .

  Source : (14)

- Nuclear Power Corporation (Whetstone)

  Turnover for April 1979 to March 1980 was £M 97 .

  Source : (9)

Table (1.5) : <u>THE FEW PUBLISHED PIECES OF FINANCIAL INFORMATION RELATING TO GEC WHETSTONE</u>

Fig. (1.1) : NON-COMMUNIST WORLD PRIMARY ENERGY CONSUMPTION

Source : Department of Energy, (1)

Fig.(1.2) : AREA LAYOUT OF THE GEC WHETSTONE SITE

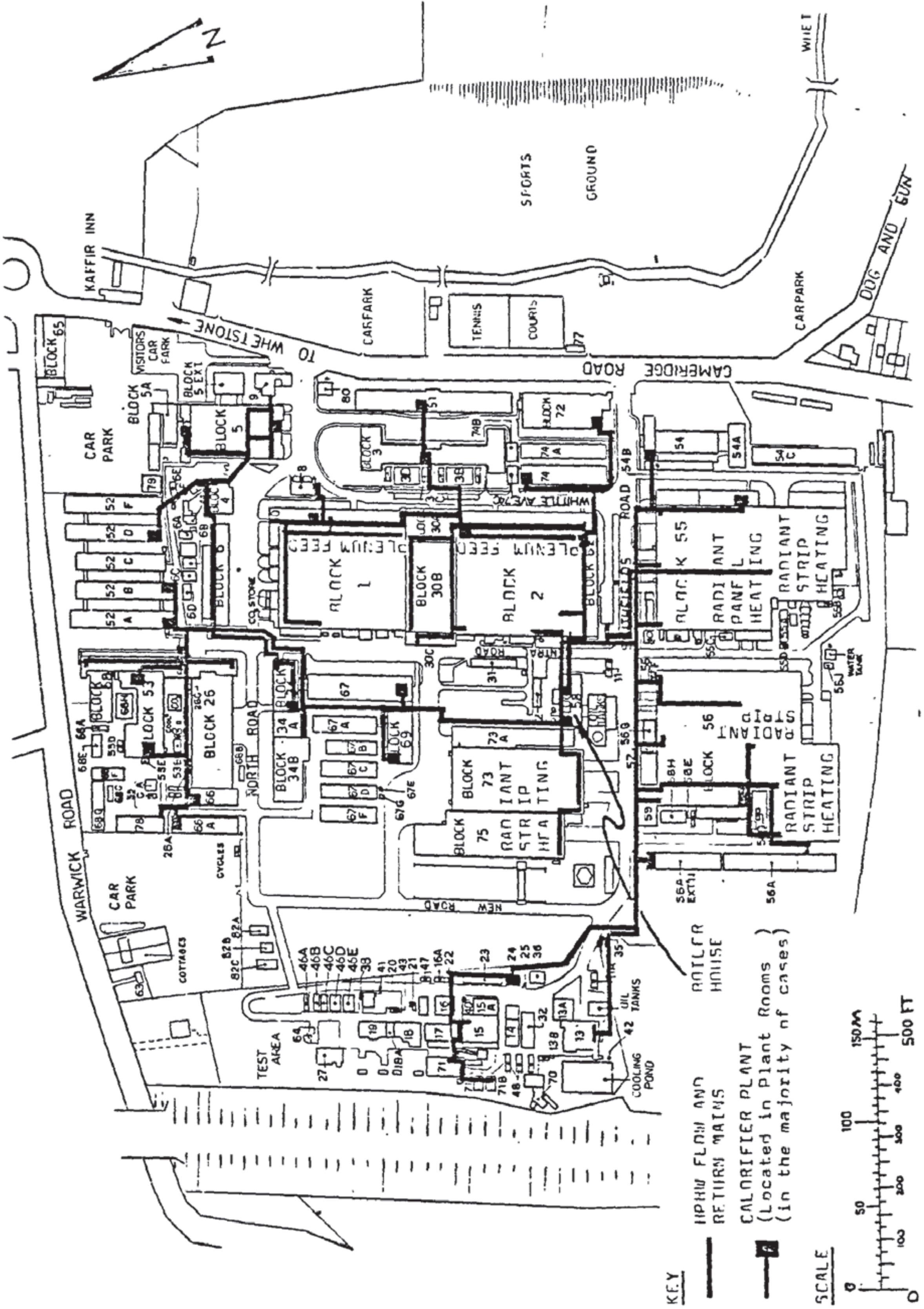


Fig.(1.3) : HIGH PRESSURE HOT WATER HEATING SERVICE

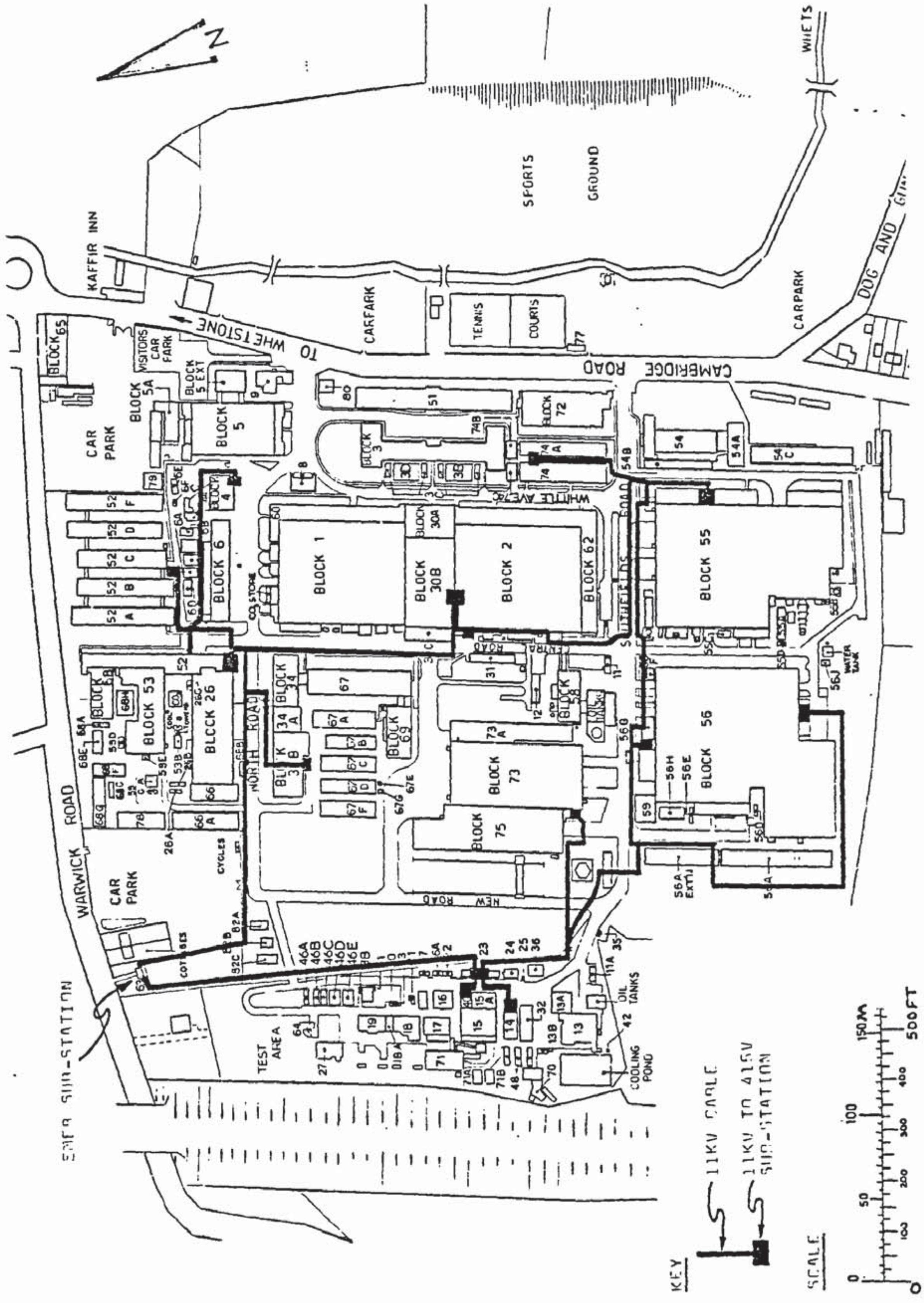


Fig.(1.4) : ELECTRICAL POWER DISTRIBUTION SYSTEM

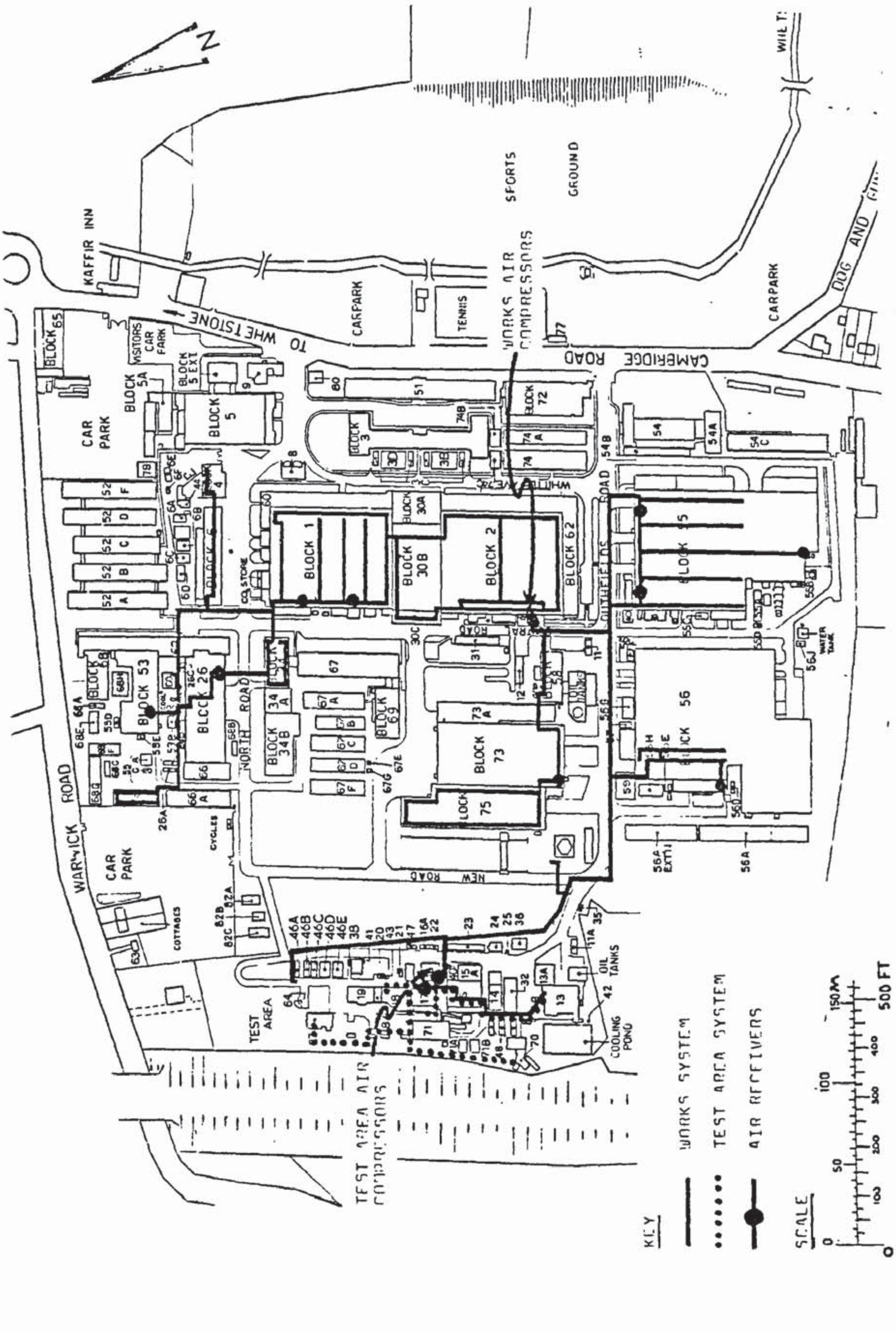


Fig.(1.5) : COMPRESSED AIR SYSTEMS

CHAPTER 2

2. INDUSTRIAL ENERGY MANAGEMENT: STATE OF THE ART AND PRACTISE AT GEC WHETSTONE

2.1 Objective

The objective of industrial energy management was stated in Section 1.3 and is to reduce the cost of energy paid for by a particular company relative to its productivity.

2.2 Literature on Energy Mangement

Textbooks about energy management have been written by a number of UK and USA authors, (18) - (25). Each states that energy management requires an understanding of accountancy, engineering and human/organisational behaviour. There is however a difference in the way UK and USA authors format their books which is a result of the different approaches that are adpoted for management development. UK authors tend to write a book as a problem-solving guide for the energy manager. USA authors tend to write their book as an input to a system of 'management by objectives' (MBO) which is widely practised in the USA, (26). MBO is a technique whereby manager and subordinate agree targets for the performance of the latter which is then reviewed periodically with new targets being set. Targets can be set aginst all responsibilities held by the subordinate although it is essential that the indicator of performance is unambiguous. Energy management through a system of MBO is achieved by introducing energy related responsibilities, targets and indicators to all levels of line management. This procedure is virtually synonymous with the ideas put forward in Chapter 1 for monitoring and targetting of heat consumption at GEC Whetstone except that through MBO the action would have been early on in the energy conservation campaign as organising for energy management, not 6 years into the programme as the 'answer to a problem'. MBO is therefore important in relation to the author's work and for this reason the USA literature is considered particularly valuable.

Despite the difference between UK and USA ways of thinking, the literature on energy management shows it to have the same conceptual content whatever the order of its implementation. Textbooks about industrial energy management cover the following topics.

(1) Energy auditing, energy surveying and energy analysis

(2) Sources of industrial energy

(3) Economics: Project appraisal techniques

(4) Physical laws: Thermodynamics, heat engine cycles, heat transfer theory, heat transport, combustion chemistry, electrical engineering sciences, control theory

(5) Energy conversion and transmission systems: steam, hot water, compressed air, electrical systems.

(6) Buildings: Fabric, ventilation

(7) Building services: Space heating, air conditioning, lighting

(8) Housekeeping: Maintenance

(9) Medium and long term investment in energy conservation technology

(10) Human/organisational behaviour and motivation

The textbook content is descriptive and theoretical. In literature which is of a general nature this is necessarily so since different industrial organisations have different energy management requirements in terms of practical measures implemented and savings made, thus 'description' and 'theory' form the only common ground. The author has adopted the above structure for the contents of this chapter but, further, has included the specific example of the GEC Whetstone programme.

The purpose of this chapter is to:

- examine the above topics as a scenario to energy management

- to show the respective development of energy management at GEC Whetstone prior to the author's work (Sections 2.4, 2.10 and 2.12)

- to examine the practise of monitoring and targetting which has emerged as a recent development in energy management not formerly practised at GEC Whetstone but which has potential to solve the organisational problems to energy saving described in Sections 1.6.3 and 1.7.

2.3 Energy Surveying, Energy Auditing and Energy Analysis

The particular steps an energy manager takes to make his company more energy efficient is dependent on a number of factors including product manufactured, the ways in which energy is used and internal company organisation. The first step in energy management is therefore to carry out an energy survey (or energy audit) of the company's site in order to plan the energy conservation compaign.

Guidelines for undertaking an energy survey are given in references (18) - (25). The simplest procedure is to use a checklist such as those given in the latter 3 references. The scope of an energy survey is described below.

(1) <u>Analyse energy consumption</u>

The aim of analysing energy consumption as part of an energy audit is an attempt at balancing total input of energy to a system with its uses in one or more consuming activities. Implicit in the achievement of a balance is that all uses, waste and inefficiency are identified and accounted. In the context of an industrial site the specific objectives are:

(a) To obtain a clearer understanding about energy costs relative to productivity on a given site.

(b) To locate distribution systems and end-uses of energy.

(c) To highlight the most energy intensive items of plant or process.

(d) To identify inefficiencies and wastage.

(e) To record energy costs and consumptions for comparison between actual and predicted or known standards of usage.

(f) To set priorities and realistic targets for energy. saving.

The approaches to analysing energy consumption are covered in references (18) - (25). Basically the analysis is begun by studying the energy bills to obtain monthly or quarterly consumptions and costs. These are then broken down in stages between the various energy conversion/transmission systems and eventually to individual end-uses. Energy balances are produced at each stage to identify the proportions of useful energy and the losses. Calculations can be estimates, based on simple measurements or from sub-metering if available. Results can be presented in the form of a Sankey diagram, pie-chart or load profile as shown in reference (24).

(2) Inspect the housekeeping of plant and buildings

The purpose of inspecting housekeeping is to determine the existing condition of plant and buildings. Checklists specifically for this purpose are given in references (21), (24) and (25). Basically, the points under inspection are:

(a) Maintenance arrangements

(b) Are the plant and buildings being used as originally intended? If not ....

(c) Are they really suitable for their present task?

(d) Are controls susceptible to unauthorised interference.

(3) Review the expertise and involvement of personnel

Positions within an organisation such as the maintenance and plant operative functions which are closely concerned with energy management should be staffed by personnel having the necessary knowledge and expertise. A manpower review in these areas should be undertaken.

The involvement of all other personnel in the energy conservation campaign through the use of promotional material, suggestion schemes and involvement of unions should be investigated. The possibilities of making individual personnel responsible for energy use in areas under their authority should be examined (c.f. Work outlined in Section 1.9 of this thesis re. GEC Whetstone). Methods for involvement of personnel are described fully in Section 2.11.

(4) Investigate investment options in energy conservation technologies

Energy conservation measures may be classified on an economic basis as follows:

(a) Short term - These measures are usually concerned with good housekeeping involving changes in operating practices or maintenance work requiring little or no capital expenditure.

(b) Medium term - Low cost modifications and improvements to existing equipment where the payback period is less than two years and often under one year.

(c) Long term - Modifications involving high capital costs and which frequently involve implementation of new techniques and new technologies.

In general, energy conservation projects have to compete for capital expenditure on the same criteria as any other form of capital investment although Government grants and tax relief, representing the wider benefits of conserving energy to the nation, are sometimes available to make investment more attractive to the company. Capital resources within a company are limited and therefore it is necessary to plan a programme consisting of short, medium and long term measures appropriate to the company's activities and within the capital budget available. The plan must yield optimum savings in terms of maximum return on investment and minimum time delay before some significant savings are made.

Individual energy conservation measures are described in Section 2.7.

(5) Carry out product energy analysis

Product energy analysis has similar objectives to the analysis of energy consumption of a given company except that the scope extends beyond the bounds of the one company in order that every input of energy to the manufacture of a product is identified. Roberts, (27) lists the aims of energy analysis as:

(a) To analyse particular processes in detail so as to deduce an energy efficiency and hence make recommendations for conserving energy.

(b) To analyse the consumption of energy on a large scale either to forecast energy demand or to point to policies which could reduce future demand.

(c) To analyse the energy consumption of basic technology such as food production and mineral extraction in order to reveal some future consequences of technological trends or an energy shortage.

(d) To construct energy costs and examine energy flows so as to understand the thermodynamics of an industrial system. This type of long-range aim may be coupled to projects such as 'world modelling' based on physical, rather than monetary, flows.

(e) Identification of possible energy savings in the energy industries, which are themselves amongst the largest consumers of energy.

(f) Identification of feedbacks as indirect energies of material and capital inputs.

(g) Determination of the more energetically favourable of two possible energy sources.

(h) Identification of any limits or 'points of futility' where no net energy is produced.

(i) Improvement of financial forecasting in evaluating the energy component of the fuel cost.

For energy analysis to lead to tangible benefits there needs to be large scale co-ordination on the matter throughout industry. For this reason energy analysis is arduous and requires significant resources. Energy analyses which have been undertaken and published are limited. Examples are work carried out by the Energy Technology Support Unit (ETSU) into the production of iron castings, (27), and work by the Production Engineering Research Association (PERA) into six products made by the engineering industries, (28).

Comprehensive methodology is described by Roberts, (27) and in a textbook by Boustead and Handcock, (29).

2.4 Energy Surveys and Audits at GEC Whetstone

Energy audits at GEC Whetstone have been undertaken on numerous occasions by Rodrigues (16) and Carroll (30). Rodrigues analysed energy consumption figures from the year 1973 until 1979. Carroll, as stated in Section 1.6.3, audited the site on 3 occasions at 3 year intervals from 1974. Rodrigues verified his analysis against those of Carroll.

The author progressed analysis of energy consumption for the year 1979/80 along the lines prescribed by Rodrigues. The analysis is shown in Table (2.1). A Sankey diagram of energy use is shown in Fig. (2.1).

For 1978/79, Rodrigues found total heating fuel consumption as 204710 GJ valued at £193656. The difference between 1978/79 and 1979/80 is partly accounted for by weather. Meteorological Office degree days for the Midland area during 1978/79 were 2523, eight per cent higher than during 1979/80 (2334 degree days). Electricity consumption during 1978/79 was 57830 GJ virtually the same as for 1979/80.

Table (2.1) identifies each energy use as either a direct use, indirect use or a loss. Direct uses are those input which power the production process. Indirect use is a fixed overhead independent of production level. If losses are apportioned on the basis of consumption by the various uses, the ratio of direct to indirect usage is:

Heating fuel: Direct = 2%
Indirect = 98%

Electricity: Direct = 38%
Indirect = 62%

These ratios are typical of a low energy intensity, mechanical engineering industrial site, (15).

Rodrigues made an evaluation of infra-red aerial thermography for detecting heat loss. Trials from overflying the GEC Whetstone site in April 1978 showed the technique to be useful for identifying sources of heat loss but it was not possible to quantify results in units of heat on temperature from thermography alone.

This section has been concerned only with analysis of energy consumption on the GEC Whetstone site. Other aspects of energy surveying in respect of GEC Whetstone are dealt with in later sections of this chapter appropriate to their methods.

2.5 Sources of Industrial Energy

Most literature about industrial energy management includes a statement of world energy consumption, forecasts and reserves usually taken from an official source such as the Department of Energy. In this thesis, this was covered in Sections 1.1 and 1.2 in the Introduction.

Industry requires mainly three types of power, namely, heat, electricity and mechanical. Any one of these three forms of power can be converted into the other two types. Heat can be used to drive a heat engine producing mechanical power which can be used to turn a generator to produce electricity. Electrical power can be conversely used to produce mechanical power in an electric motor or heat in a heating element. Any conversion process is never 100% efficient. Furthermore, heat engine efficiencies are governed by the thermodynamic laws and material temperature limits which means that heat can only be converted into mechanical power at little over 30% efficiency (Section 2.7.3). Virtually all electrical and mechanical power is produced in this way with heat being derived from combustion of fossil fuel or nuclear fusion and the 70% or so waste heat being dissipated uselessly to the environment.

Clearly, it is a bad practice to use electricity for heating when fuels can be combusted on site for heat generation at efficiencies of between 70 and 85%. The following is a list of fuels supplied to industry for heat raising:

Natural gas

Coal - Various grades and types

Oil - Kerosine
Gas oil (Class D, 35 sec.)
Light fuel oil (Class E, 200 sec.)

Medium fuel oil (Class F, 950 sec.)

Heavy fuel oil (Class G, 3500 sec.)

LPG

Other sources of heat are being harnessed with the onset of energy conservation throughout industry. The main sources are:

(a) Incineration of waste

(b) Combined heat and power - the harnessing of the 70% or so waste heat from mechanical and electrical power generation.

(c) Recovery of heat from other higher temperature heating processes.

Methods of producing heat from these sources will be described in Sections 2.9.2 and 2.9.3.

2.6 Methods of Financial Appraisal of Projects

Energy conservation measures have to compete for capital allocation in a company's budget as stated in Section 2.3 Techniques for appraisal are as follows:

(1) Rate of return

The basic principle of this technique is that the investment of additional capital must earn an adequate remuneration for its owners. It is calculated by expressing the average annual net income from the project, after depreciation, as a percentage of the capital cost.

(2) <u>Payback method</u>

The payback period is the length of time required for savings to equal the capital investment of the project. Using this technique, the shorter the payback period the more desirable the investment. The method is particularly useful for short and medium-term energy conservation projects.

At GEC Whetstone, the Estates Manager used the payback method exclusively.

(3) <u>Net present value (NPV)</u>

A disadvantage of both rate of return and payback is that they do not take into account the timing of returns on investment. Savings occurring earlier in a projects lifetime are more valuable than those made later since they can be reinvested to make other earnings predicted to be the compound interest earnt at the test discount rate.

In net present value calculations all outgoing expenditures (capital, maintenance, consumables etc.) and income from savings, grants and sale of scrap at the end of the project are discounted according to the year in which they occurred to give net present value. The discount rate is chosen to be representative of the cost of capital to the company and therefore projects with negative NPV can be rejected outright. The preferred investment amongst competing projects is the one with the highest positive NPV (subject to capital availability). Details of calculations are given in reference (31).

(4) Modified discounted cash flow method

The method suggested by James (32) is based on standard discounted cash flow but makes adjustment to the value of energy saved according to anticipated growth in future energy costs.

(5) Internal rate of return

Internal rate of return is also based on discounted cash flow. The method operates to find the discounting rate which gives an NPV of nil. The discounting rate so obtained can be compared firstly with the company's cost of capital and then used for comparison of competing projects. The method is also known as the discounted yield method and details of calculations are given in reference (31).

(6) Life-cycle costing (LCC)

LCC is a concept from the USA (33), and not widely used in the UK. It is based on the premise that only the real life expectancy of an energy saving measure should be used in the estimate of time preceding absolescence. This, it suggests, is the only limiting factor. The method rules out other definitions of life expectancy for equipment since with systematic maintenance, irrespective of cost, equipment life can be indefinitely extended.

The method uses the traditional straight payback constant which is dimensionally in years. The formula for this constant is different, however, expressing differential investment against differential return. The method is useful when considering competing energy saving schemes because incremental capital costs and incremental operating costs are compared. The sensitivity factor in these calculations is obviously the view taken about life expectancy as defined by the method.

2.7 Physical Laws and Phenomenon governing Energy Conversion/Transmission/Utilisation and Concepts leading to Energy Conservation in Industry

Murphy (18) and O'Callaghan (22) devote about one third of their textbooks to the understanding of physical models and laws characterising energy flows in industrial plant and the implications for energy conservation. An energy manager, whether it be the company energy manager or a line manager with partial delegated energy management responsibility, must be able to recognise the technical grounds were there is an opportunity for energy conservation. Energy surveys and energy audits (Section 2.3), whilst presenting a picture of energy use are useless unless the information gathered is analysed for conservation potential using a knowledge of physics and engineering science to first recognise the opportunity, then to quantify it and finally put forward the case for investment.

Fundamental to energy management is the understanding of the following, (References (18), (22)).

- Heat transfer
- Heat transport
- Thermodynamics (heat engines)
- Combustion chemistry
- Electrical engineering science
- Control engineering

2.7.1 Heat transfer

Heat transfer can occur in three ways namely conduction, convection and radiation. The mechanisms are different in each case although the fact that a temperature difference is necessary is common to all. A useful treatment of heat transfer theory is given by Mayhew and Rodgers (34).

Conduction

Heat transfer by conduction involves the transfer of energy on a molecular scale. The analysis of conductive heat transfer is based on Fourier's law of heat conduction describing one dimensional steady heat flow through a solid. This states that heat flow is proportional to the area of heat flow and the temperature gradients within the solid. The constant of proportionality is called the thermal conductivity of the solid.

Convection

Convection is a mode of heat transfer which occurs when temperature differences exist between a fluid and solid boundary. The mechanism of transfer is partly due to conduction and partly due to the motion of the fluid itself. The fluid motion can be mechanically pumped or due entirely to buoyancy effects caused by the temperature gradients. Convection in the first case is termed 'forced convection' and in the later 'natural convection'.

Analysis of convective heat transfer is not simple. There are many variables such as velocity of flow, thermal conductivity, viscosity, density and thermal expansion of the fluid. Boundary layer phenomenon (the behaviour of the fluid immediately adjacent to the solid boundary) is important in modelling convective heat transfer, refer to Mayhew and Rodgers (34).

Radiation

Heat transfer by radiation involves the emission and absorption of electromagnetic waves. All matter at temperatures above absolute zero emits electromagnetic waves. A black body radiator (a surface with absorbtivity equal to 1 and transmissivity and reflectivity equal to zero) is comparatively simple to analyse in terms of energy emitted. The total energy emitted per unit time by a unit area of black surface is proportional to the fourth power of the absolute temperature, as expressed by the Stefan-Bottzmann law.

$$q_b = \sigma T^4$$

where σ is called the Stefan-Boltzmann constant; it is equal to 56.7×10^{-12} $kW/m^{2o}K^4$, when energy emitted per unit q_b is measured in kW/m^2 and T in ^oK. Many cases of radiative heat transfer in industrial situations can be analysed by approximation to black body emmission.

Combined modes of heat transfer

Most practical heat transfer involves conductive, convective and radiative modes. In energy management there is interest concerning heat transfer in three main areas:

(1) Boiler plant - transfer of heat from products of combustion in the furnace to the water contained in the tubes or shell of a boiler.

(2) Heat exchangers - transfer of heat from one fluid stream to another such as in calorifiers, heater batteries and heat recovery systems.

(3) Building fabric losses - 'U' values given in $W/m^{2\,o}K$ are co-efficients representing the combined conductive, convective and radiative heat transfer performance of materials used in building applications. 'U' values for various building fabrics are given in many sources of which the CIBS Guide (35) is probably the most comprehensive. The basic equation using 'U' values is

$$Q_F = \sum_{\text{all materials}} U_i \, A_i \, (T_I - T_o)$$

where: Q_F is the heat loss through the fabric of the building in watts

U_i is the 'U' value of material type i

A_i is the area of material type i in the building

T_I is inside temperature

T_o is outside temperature (average, design etc.)

Note: There are other heat losses from a building such as the infiltration loss caused by warming of air for ventilation from the outside temperature to the level of inside temperature. Another loss is intermittently heated buildings is the thermal capacity of the building structure which absorbs heat during heated periods and releases it during unheated periods. These are not losses which occur by direct heat transfer mechanisms. The subject of space heating buildings is dealt with more thoroughly in Section 2.8.

At GEC Whetstone, Rodrigues made an assessment of all building fabric heat losses. The results appear in his thesis (16).

2.7.2 Heat transport

Heat transport is the movement of heat as internal molecular energy of a fluid moved along a conduit by essentially mechanical means and not by temperature difference as in heat transfer. The usual arrangement in an industrial situation is to move a heated fluid around a circuit using a pump or other forced circulation. Fluids commonly used are water, steam, air, oil and refrigerants. An example of application is a central boiler house where heat is transferred to a water circuit which distributes to remote calorifiers where the heat is transferred from the water to supply heating.

Addition of heat to a pure substance

A pure substance has a homogeneous and invariable chemical composition even though it undergoes a change of phase. A substance can exist as solid, liquid or gas. As heat is added to solid phase its temperature rises until it begins to melt. As melting progresses, with the addition of more heat, the temperature remains constant. The heat added during melting is termed the 'heat of fusion'. Continued addition of heat to the liquid phase again causes the temperature to rise until the liquid begins to boil. The boiling point is a function of pressure and is also known as the saturation temperature. Whilst liquid phase is present, the addition of the heat of vapourisation in the boiling process takes place at constant temperature. Once the liquid phase is removed the vapour becomes superheated as further heat is added.

The above is a very simple description of the behaviour of a substance when heated. The thermodynamic state of a pure substance can be defined by pressure, temperature and specific volume. The relationships are complex and for practical application tables are used such as those for water and steam produced by Mayhew and Rodgers (36).

2.7.3 Heat Engines

A heat engine is any system operating in a cycle and producing a net quantity of work from a supply of heat. The greater the proportion of heat converted into work, the better the engine. There are the first and second laws of thermodynamics which dictate the best efficiency that can be achieved in a given heat engine.

First Law of Thermodynamics

The first law of thermodynamics states that when any closed system is taken through a cycle, the net work delivered to the surroundings is proportional to the net heat taken from the surroundings.

Second Law of Thermodynamics

There is nothing implicit in the first law to say that net heat taken from the surroundings cannot all be converted to work. The second law is an expression of the fact that in a practical heat engine cycle some heat must be rejected. The law may be stated in the following form: "It is impossible to construct a system which will operate in a cycle, extract heat from a reservoir and do an equivalent amount of work on the surroundings." If energy is to be supplied to a system in the form of heat, the system must be in contact with a reservoir at a temperature higher than that of the fluid at some point in the cycle. Similarly, if heat is to be rejected, the system must at some time be in contact with a reservoir of lower temperature than the fluid. Thus the second law implies that if a system is to undergo a cycle and produce work, it must operate between at least two reservoirs of different temperature.

Reversible Engines and Carnot Efficiency

A reversible engine operates a cycle where all processes are reversible. Reversible processes are where heat flow must be by virtue of infinitesimally small temperature differences and work must only be done when the force exerted by the surroundings on the moving boundary is infinitesimally different from the force due to the pressure of the fluid in the system. The efficiency of a reversible engine is governed only by the first and second laws of thermodynamics and can be shown to be, (Reference (34)):

$$\eta_c = 1 - T_2/T_1$$

where η_c is known as the Carnot efficiency

T_1 is the hot source temperature in ^oK

T_2 is the cold sink temperature in ^oK

Practical Efficiencies

In practice a cold reservoir means dissipation to the environment, either to the atmosphere or to the sea, at a temperature nominally taken as 288^oK. A hot reservoir requires some process of combustion or nuclear reaction. Temperatures at which the hot source can be allowed to operate are currently limited by material temperature limits which are approximately as follows:

Steels used in steam turbines	:	900^oK
Alloys used in gas turbines	:	1000^oK
Materials used in nuclear power plant	:	700^oK

Higher temperatures can be permitted in internal combustion engines where the heat source is intermittent and therefore there is overall less heating of the material parts. Nevertheless the upper thermodynamic efficiencies for power plant are bounded quite sharply by material temperature limits and the temperature of the environment.

In addition to thermodynamic inefficiency there are mechanical inefficiencies such as friction and size/weight limitations imposed on the working parts of machinery. These factors place further constraints on the minimum achievable exhaust temperature and therefore increase reject heat from an engine. To partially overcome some of the limitations imposed many different heat engine cycles have been devised and are discussed in many textbooks about thermodynamics such as reference (34). The current state of development in engine technology achieves the following efficiencies:

	Best efficiencies to date Heat to Mechanical (%)
Steam turbine, Fossil fuelled	40
Steam turbine, Nuclear (AGR)	41
Gas turbine	30
Diesel engine	41
Spark ignition engine	29

(Source: Reference (37))

This section about heat engines has brought out two important considerations for energy conservation. The first is grading of heat according to temperature above ambient. A higher temperature source is more valuable than a cooler source. Particularly, when the heat source is a waste heat source, the number of possibilities for re-use are enhanced the higher the temperature and also it is easier to recover the heat. The second point of consideration is the use of reject heat from power generation as a waste heat source. The best power generation efficiency is achieved by exhausting at ambient temperature but then the reject heat is totally useless. If there is a suitable heat load to be satisfied consideration can be given to exhausting waste heat at a temperature high enough to supply the heat load. Power generation efficiency is reduced but overall thermal efficiency can be two- or three- fold increased because usable heat is also being provided. Such arrangements are called combined heat and power (CHP) schemes and have been used on industrial sites and in district heating schemes. Rodrigues (16) made extensive investigation of the applications of CHP and subsequently prepared plans for a scheme at GEC Whetstone. Further details are given in Section 2.9.2.

2.7.4 Combustion Chemistry

The term combustion refers to the fairly rapid reaction, usually accompanied by a flame, which occurs between a fuel and an oxygen carrier such as air. The molecules of fuel and air have a certain amount of energy stored in the bonds between their constituent atoms. In the new molecules formed by a combustion reaction this chemical energy is at a lower level and the energy thus released can be transferred to the surroundings in the form of heat. Combustion is therefore said to be an exothermic reaction.

Fuels

The fuels for industrial use listed in Section 2.5 consist mainly of carbon and hydrogen which exist as hydrocarbons in petroleum and natural gases or, as in the case of coal, as graphite carbon. Coal does also contain between 5 and 10% hydrocarbons trapped within the solid material.

Combustion reactions

Complete combustion of hydrocarbon fuel leads to the formation of carbon dioxide and water vapour. Incomplete combustion where there is insufficient oxygen supply leads to the release of carbon monoxide and possibly some unburnt carbon and/or hydrogen in the combustion products. The presence of these partially combusted products represents a waste of energy in that they contain a higher level of chemical energy than carbon dioxide and water vapour.

In industrial combustion systems the supply of oxygen is obtained by mixing fuel with air. As well as supplying oxygen, nitrogen is present in air in a volumetric ratio of 21% oxygen to 79% nitrogen. The nitrogen takes no part in the reaction but appears in the combustion products. A fuel/air mixture containing the correct quantity of oxygen for complete combustion is called a stoichiometric mixture. In practice the time available for combustion is limited and excess air must be provided if complete combustion is to be provided. The temperature of combustion products is determined by the flow rate and their specific heat. The quantity of air and particularly excess air and inert nitrogen associated with it has a large influence over the temperature of combustion products. A high temperature is desirable since this makes heat transfer from the combustion process more powerful and also enables a higher grade of heat (c.f. Section 2.7.3). The control of air quantity to achieve complete combustion yet not unnecessarily cool the combustion products is therefore important.

Combustion reactions for different fuels and their anaysis are dealt with in references (34), (38) and (39). Basically there are the three parameters mentioned above which are of interest namely air quantity, heat generated and temperature of combustion products. Air quantity is derived from the mol analysis of the chemical equation for the combustion reaction. Heat generated is calculated from the 'change in enthalpy' from reactants to products and temperature of combustion products is found from the temperature rise caused by the release of this energy into the reactants/products stream. The heat derived from complete combustion of a unit quantity of a given fuel and subsequent cooling of products to the same temperature as the reactants is termed the calorific value of the fuel. A number of calorific values for a fuel are distinguished.

(a) Gross calorific value at constant volume where the water in the products is condensed to liquid.

(b) Net calorific value at constant volume where the water in the products in vapour.

(c) Gross calorific value at constant pressure (water in products as liquid).

(d) Net calorific value at constant volume (water in products as vapour).

The difference between gross and net values is the latent heat of the water vapour. In industrial combustion systems burning fuel oils it is not possible to achieve the gross calorific values because small quantities of sulphur present in the fuel which burn to sulphur dioxide and then combine with water to give sulphurous acid which attacks steel components of heat transfer surfaces and flue ways. When burning natural gas it is possible to operate to the gross calorific values.

The difference between constant volume and constant pressure calorific values is very small and represents the work done at constant pressure by changes in volume due to number of molecules (mols) of gaseous reactants against number of molecules present as products after combustion.

2.7.5 Electrical Engineering Science

As stated in Section 2.5, electricity is generally regarded as an expensive form of energy since the overall efficiency of electrical generation from fossil fuel in a power station is around 30%. However, electricity has advantages in ease of control, high energy transfer efficiencies at the end-use and freedom from pollution.

Electrical machines

Production of mechanical power in an electric motor is at efficiencies of between 80 and 90% depending on the type and size of motor, (40).

Heating

Heating of material can be accomplished at high efficiency using electricity via direct resistance heating (passing a current through the material to be heated), electromagnetic induction, arc or plasma-arc, dielectric loss or microwave absorption, (37).

Lighting

Types of lamps found in industry are described by Murphy (18) which are in 4 categories:

		Luminous efficacy (Lumens/W)
Incandescent	- Heated white hot filament	8 - 18
Fluorescent	- Fluorescent coating excited by electrical discharge	20 - 65
Mercury vapour	- Mercury vapour excited by electrical discharge	40 - 70
Sodium	- Sodium vapour excited by electrical discharge	55 - 110

Energy savings can be made by installing one of the more efficient electrical heating methods and, for lighting, by changing to more efficient lamps such as fluorescent and sodium.

Other electrical savings can normally be made on an industrial site as follows:

(1) Power Factory Correction

Most electrical equipment which contains 'wound' components, for example electric motors and transformers, presents an inductor reactive component of load to the power supply system which is additional (vectorially) to the real power being converted to motive power, heat etc. Inductor reactive loads do not consume power but store and source energy from the magnetic field associated with a wound component. However reactive power increases the level of current flowing in an electrical system and increases the power dissipated in the resistance of cables and transformer windings. The ratio of real power divided by the vectorial addition of real plus reactive power in a given electrical system is called the power factor.

Inductor reactive power can be generated local to an inductive load by connection of a capacitor which imposes a reactive load that is vectorially 180^{0} out of phase (i.e. a generator) with the inductive loading. By selecting a suitable size of capacitor (Say, (40)) the reactive current loading on distribution cabling and transformers can be minimised thereby reducing losses in cable and winding resistances.

(2) Controls

Electrical usage can be controlled using time switching and/ or feedback loop controls. A more detailed description of controls is given in Section 2.7.6. Here it will suffice to say that time switching means that items of plant are switched on and off according to programmed requirements and feedback loop control means that the output from a motor, heater etc. is modulated according to instaneous demand on the plant. There are number of methods of achieving variable output from electrically powered plant and these are described by Say, (40). It must be recognised that some of the simpler methods described in this reference do not lead to reduced electrical consumption since they merely dissipate surplus power in a rheostat or load resistor. There are always alternative energy efficient methods in these cases. Variable voltage transformers can be used to replace rheostats. Load resistors, such as those used to vary the speed of 3-phase induction motors, can be replaced by an inverter which converts the surplus power to mains voltage and frequency for reinjection to the mains distribution system. (The Kramer system, (40)).

(3) Tariff Analysis

Tariff analysis undertaken by a consumer aims to secure the lowest price for the electricity used. Energy savings are not primarily involved as far as the consumer is concerned.

Area Electricity Boards offer a range of tariffs for different users, for example, domestic, industrial, commercial and farming. The commercial and industrial groups are further sub-divided according to annual consumption or supply capacity. The first stage in tariff analysis is to verify that the most suitable tariff is being used.

The second stage is to examine the elements of the tariff. Industrial tariffs generally contain the following charges although this does vary between area electricity boards.

Fixed charge - based on supply capacity.

Consumption charge - based on KWh consumed, which may be broken down into day, night and evening/weekend units.

Maximum demand charge - based on the annual maximum demand assessed by measuring the highest KWh consumption over a half hour period.

Power factor charge - based on the monthly average power factor.

Fuel cost adjustment - surcharge for variations in fuel cost to the Central Electricity Generating Board levied on a per unit basis.

Minimum monthly charge.

The consumer has a measure of choice over the consumption, maximum demand and power factor charges. The consumption charge can be reduced by re-scheduling operations to the periods of lower rate such as overnight heating of hot water and overnight charging of electric vehicle accumulators. The maximum demand charge can be reduced by re-scheduling production activities occurring during the critical maximum demand period. Power factor charges can be reduced as previously described in this section. Although only power factor correction results in actual KWh savings as far as the consumer is concerned, the modification of load factor through lower night rate charges and maximum demand penalties enables the Central Electricity Generating Board to use the most economical power stations in their merit order.

2.7.6 Control Engineering

In any control system, the control is based on the regulation of a physical quantity such as temperature, pressure, flow etc. In the context of energy conservation controls are applied to plant in order that set conditions of temperature, pressure, flow etc. are maintained in processes or building environments by regulation of energy input. In elementary terms, the contribution made to energy conservation by control is that when process or space conditioning plant is working at less than design capacity the energy inputs can be turned down proportionally and thus avoid wasting energy.

Control engineering is a complicated subject with the most exacting state-of-the-art theories and standards being practised in the control of aircraft and spacecraft. For the energy manager, the 63 page treatment in Dryden (37) is a good grounding.

Any type of controller, manual or automatic needs three continuous inouts:

(1) The signal representing the value of the quantity being controlled (the measured variable).

(2) A required level of the measured variable (desired value). This is usually in a memory either physically pre-set or memorised by a human operator or stored digitally in micro-processor and computerised control systems. The desired level can be a variable, for example, a function of time.

(3) A power supply - electric, pneumatic, hydraulic or human.

The controller performs an algebraic subtraction of measured and desired values to determine magnitude and direction of the error. This is then operated on mathematically (to give stability, stiffness and responsiveness to the control system as described later) resulting in a signal which causes the process to proceed at a new datum where the measured value of the physical variable is near to the desired value. The signal from the controller can be applied to the process in one of two distinct ways known as 'open-loop' or 'closed-loop' control.

Open loop control uses a causative measured variable compared against a corresponding desired value which acts through a transfer function (the input-output characteristic of the control loop) to control a process. The transfer function has to be known precisely in mathematical terms if the system is to control the process in the desired manner. Also open loop control has no way of responding to a disturbance in the process which is not related to the measured variable in use.

An example of open loop control is the 'compensator' manufactured by Satchwell (41) and others. This control device attempts to maintain a constant building internal temperature by regulating space heating system output in an inverse linear relationship with outside temperature. Clearly the system has no control over, say, heat gain due to electrical usage in the building.

Closed loop control uses a measured variable which is fed back from the conditions in the process under control. Such a system can accommodate disturbances. These are allowed to enter the process and measurement is made of the actual quantity to be controlled. The controller feeds back a signal to cause the process to proceed with correction for the disturbance.

An example of closed loop control is the use of an internal space temperature thermostat to control heating in a building.

Three features of closed loop control are that:

(1) The controller 'sees' the result of its action.

(2) Because of this, it is possible for the system to oscillate if the controller action is too great for a unit error. A finite time must elapse between controller action and the result of the action arriving at the sensor, and the controller may have overcompensated. This condition is known as 'hunting'.

(3) Some departure from the desired value must occur to produce an error to initiate controller action.

In order to influence the oscillatory nature (stability) of a closed loop control response, derivative action can be added to the straight forward proportional response. Derivative control introduces damping into the response.

In order to correct the offset problem (stiffness of the control system), integral action can be added to proportional control. The integral action, over a period of time, finds a correction for the offset which is applied to the controller.

Digital control

A controller can be made a digital processing device. To facilitate this, primary measured values have to be translated from analogue to digital code and controller outputs have to be converted from digital to analogue form. The main advantage of a digital system is the ease with which sophisticated control strategies can be programmed into the digital processor. A microprocessor or computer is capable of accepting a number of measured variables and their corresponding desired values (as functions of time if necessary), undertake computation of proportional, derivative and integral terms for a number of outputs and even self-adapt its response characteristic based on learning from the way the process behaves.

Self adaptive control is a valuable technique in the industrial field because in most cases it is very difficult to mathematically model the behaviour of a process. An example of this is the modelling of thermal response for a building. In simple terms, the rise in internal temperature from commencement of heating would be the solution to a differential equation involving net heat into the building (heating system output minus the internal temperature dependent fabric and ventilation loss) and the thermal inertia of the building structure. However, other factors such as response to wind speed and direction, solar gain and changes in outside air temperature during warming up make the model unreliable. Improvement to the model and extensive validation in individual buildings would be required and this is out of the question on a site like

GEC Whetstone where there are approximately 30 buildings to be considered. One reason for wanting to know the thermal response of a building is so that the optimum time for commencement of heating the building prior to occupancy can be computed. From the simple thermal inertia model, it can be seen that this time is variable and is a function of inside and outside temperatures. A control device known as the self-adaptive optimiser manufactured by Satchwell (41) and others can be installed to predict the correct time for switch-on of the heating. This device is micro-processor based with digital storage and it learns and remembers the building thermal characteristic at different internal and external air temperature conditions as measured by its own sensors. The predictive nature of the control is further refined by generating an external air temperature daily profile and not relying on a single point-in-time current measurement. The daily profile is learnt from historical measurements and is slowly modified throughout the year to take account of seasonal variation.

Electronic Energy Management Systems

A development in digital control technology currently taking place is the integration of all energy controls on a given industrial site by linking them to a central computer. Such systems are called electronic energy management systems (EMS). The advantages of this are put forward in the ASHRAE

Handbook (42) and are essentially that the measurements made by the control sensors are available from the central computer and enables site management to determine that the correct process conditions are being maintained and that the controls are performing reliably. Any corrective measures can be programmed into the system at the central computer which may be set point changes, re-programming of control strategies or running a diagnostic program to ascertain a repair or maintenance schedule for the plant.

Controls which are put under the supervision of an EMS can be, process, production, space heating, hot water service and lighting. The different types of control are discussed in Section 2.9.4.

2.8 Buildings and Building Services

Buildings are an important category of energy consuming 'plant'. As described in Section 1.4, 40 - 50% of gross UK energy supply is destined for use in buildings for space conditioning. For this reason this section is devoted to the subject of buildings and heating, ventilating, air conditioning (HVAC) systems. The majority of the information has been obtained from the CIBS Guide, (35).

There are a number of factors which influence the environment within a building:

(1) Heat loss or gain through the walls, roof and floor.

(2) Heat loss or gain through ventilation of the building.

(3) Heat lost or gained from the structure of the building during warming-up or cooling-down.

(4) Internal gains from plant, electrical machines and people.

(5) Solar gain on the building fabric.

(6) The type of heating system employed: warm air types, radiant types and air conditioning.

(7) The hours of use of the building and whether intermittent heating is involved.

There exists some sophisticated models of building thermal behaviour taking into account all of the above factors, references (43) - (45) and (35). Basically they model a building as a heat flow system where, for a heating situation, there are heat inputs from internal gains, solar gain and the heating system and heat losses via walls, roof floor, ventilation and to the structure. Heat loss through the fabric is represented by the conductive heat transfer equation but with 'U' values as described in Section 2.7.1 Heat loss by ventilation, which may be natural or mechanical using fans, is a heat transport phenomenon (Section 2.7.2). The magnitude of both these heat losses is directly proportional to the temperature difference from outside to the required inside. Clearly, these losses diminish as outside temperature rises and there is a temperature at which the internal gains alone will maintain the required internal temperature without any input from the heating system. The outside temperature at which this occurs is called the balance temperature for the building. If outside temperature rises further cooling is required if the desired internal temperature is to be maintained.

There are a number of arrangements for heating and cooling:

(1) Radiator Systems

Radiators are installed throughout a building and transfer heat to the space mainly by natural convection and to a lesser extent by radiation. The radiators themselves are heated by a flow of hot water or steam. When medium/high pressure hot water or steam is used directly in a radiator system the radiators are enclosed for protection against scalding. This type of radiator is commonly termed a convector.

(2) Warm Air Systems

Warm air systems consist of a unit containing a heat exchanger matrix and a fan which blows air through it. Heat is supplied to the matrix by either hot water, steam or combustion products from direct firing. Heat transfer to the air stream is by forced convection. The stream of hot air can be supplied down ductwork to the building space or the warm air unit can be situated actually in the space as with the 'unit heater' and 'fan convector'. The cold air to the unit may be taken from the building space (recirculation) or from outside (fresh air input) or a mixture of both (partial recirculation).

(3) <u>Radiant Systems</u>

A radiant system is designed to emit a high proportion of radiant heat relative to conduction and convection components. The radiation, which is predominantly infra-red band, does not heat the air volume of the building directly but passes through it to be absorbed by bodies and thereby heating them. A radiant heating emitter usually requires a source temperature of 150°C or higher which can be provided by high pressure hot water, steam or gas firing. Gas firing is a relatively new technique and is described more fully in Section 2.9.3. Radiant emitters are usually mounted overhead.

(4) <u>Air Conditioning</u>

Air conditioning is an advancement of the warm air type of to include not only heating but cooling and also humidification/dehumidification. A 'full' air conditioning system consists of a plant which supplies air to and takes return air from the building space. Basically this air stream is recirculated through cooler and heater batteries in the plant where heat can be removed or added respectively to maintain the desired space conditions which are usually monitored for control purposes by sensing the return air. A variable quantity, between 0% and 100% of the return air can be exhausted to outside with a corresponding volume of fresh air being drawn in at the plant in order to provide for ventilation of the building. Humidification is achieved by spraying water or injecting steam into the supply duct. Dehumidification is achieved by cooling the air with the cooler battery so that water vapour condenses and is drained away. The air is then reheated with the heater battery to the required supply air temperature.

Buildings at GEC Whetstone

Rodrigues (16) made a survey of buildings on the GEC Whetstone site in terms of fabric heat loss, ventilation heat loss and types of heating system employed.

2.9 Energy Conservation Technology

The various avenues for practical energy conservation are based on the theory described in Section 2.7. To recap there are the following avenues for industrial energy conservation:

(1) Insulation of hot bodies, e.g. pipes, tanks and buildings.

(2) Thermal Bettering e.g. CHP and heat recovery.

(3) Alternative fuels including advanced combustion systems and the burning of waste.

(4) Electrical system optimisation (as Section 2.7.5).

(5) More efficient lighting (as Section 2.7.5).

(6) Automatic controls.

(7) Material substitution in products with alternative having low intrinsic energy content.

(8) Change processes.

The above avenues basically involve the installation of a piece of hardware. To this list three somewhat more abstract concepts can be added:

(9) Maintenance - Maintaining plant in the best working order with the intention that this gives the most energy efficient operation.

(10) Doing without e.g. Lowering standards of comfort.

(11) Line management and workforce involvement and motivation. This is described in the following Section 2.10 and it was this avenue that developed into the author's work at GEC Whetstone.

It is impossible to describe every application of energy conservation technology because these are very varied taking into account all the specialised situations that exist throughout industry. The remainder of this section is a brief description of the more common measures which are applicable generally on an industrial site. The descriptions given outline the principles and give where possible typical payback periods for the measures taken according to references (18) - (25) and the Department of Energy, Energy Conservation Demonstration Projects Scheme Project Profiles (46).

2.9.1 Insulation

Three types of hot body common in the industrial environment which should be insulated against heat loss are:

(1) Pipes and tanks

(2) Buildings

(3) Furnaces, Kilns etc.

Pipes and Tanks

A wide range of pipe and tank insulation products is available and are commonly preformed sections made from rock or glass fibres, calcium silicate or magnesia, polyurethane or polyisocyanurate depending upon the working temperature, (47). Payback on pipe and tank insulation is typically 0.5 to 2 years depending on the temperature of the pipe or tank, the level of insulation applied and the hours per annum of plant operation.

Buildings

For buildings there is again a wide range of insulation products available for application to both roof and walls, (48). The insulation materials are commonly rock or glass fibre, polyurethane or polystyrene based. Methods of application vary. The materials can be blown or foamed into cavities or used in sheet or quilt form for fixing directly to roof and wall internal surfaces. Polyurethane can also be sprayed onto external roof and wall surfaces. Payback on building insulation depends on hours per annum the building is operated and the 'U' value of the existing fabric. The range of payback is from 2 years for a continuously heated building insulated to achieve a 'U' value of 0.6W/m^2 from previous 6W/m^2 (single sheet steel or asbestos) to 7 years for a building occupies 10 hours per day with 'U' value improvement from

$3W/m^2$ (typical uninsulated office building roof) to $0.6W/m^2$, (48).

Furnaces and Kilns

Kilns and furnaces can have insulation applied for two reasons the first being to minimise heat loss from the hot space to ambient through the kiln or furnace wall. The second reason, where the kiln or furnace is used on an intermittent cycle, insulation can be used to minimise heating up and consequent cooling down of the wall itself. In this case the type of insulation used is ceramic fibre which has low thermal conductivity and low thermal capacity and is applied to the internal surfaces of the kiln or furnace. Payback periods are usually less than 2 years being dependent on hours per annum operation, intermittency period and furnace operating temperature.

2.9.2 Thermal Bettering

The principle of thermal bettering were described in Section 2.7.3 as involving the harnessing of waste heat from a source which is matched with a demand for heat in terms of temperature or grade of heat, quantity of heat and timing. (i.e. Do the times when waste heat is sourced from a given process correspond to the times when it is required by another?) Basically, implementation of thermal bettering involves finding a source/demand match and then employing a heat exchanger. A number of types of heat exchanger exist:

(1) Waste heat boiler

(2) Shell and tube heat exchangers

(3) Plate type heat exchangers

(4) Run round coil system

(5) Recuperators

(6) Regenerators

(7) Heat Wheels

(8) Heat pipes

(9) Heat pumps

Waste Heat Boiler

A waste heat boiler is employed in CHP systems where the exhaust gases from a diesel engine or gas turbine are fed through primary tubes of the boiler in order to raise steam or hot water for heat supply.

Shell and Tube Exchangers

The waste heat transport medium is circulated through a primary tube bundle which is imersed in the secondary (recovery) circulation contained in the shell. Typical applications of the shell and tube heat exchanger include heat recovery from hot effluent streams such as boiler blowdown, waste wash liquors, waste gas streams, solvent cooling and process fluids.

Plate Type Heat Exchangers

Plate type heat exchangers consist of a series of separate parallel plates forming thin flow passages. Each plate is separated from the next by gaskets and the primary stream passes in parallel through alternative plates whilst the secondary stream passes in parallel between the hot plates. The advantages of this type of heat exchanger are the ease of cleaning, ability to add additional heating surface if heat recovery conditions alter and ease of replacement of faulty plates or gaskets. Applications are therefore typically where one or both of the primary or secondary fluids is dirty or aggressive such as in heat recovery from dyehouse effluents and flue gases.

Run around coil system

A run round coil system consists of two heat exchanger coils installed in the inlet and outlet ducts of two air streams and connected to each other by pipework filled with a continuously circulating water mixture. Exhaust air passing through the outlet heat exchanger warms or cools the circulating liquid which is then passed to the inlet coil where there is heat exchange with the inlet stream. An advantage with the system is that the inlet and outlet ducts can be remote from each other and the pipework in which the liquid circulates can be installed to suit.

Recuperators

Recuperators are heat exchangers in which heat in exhaust flue gases are transferred to preheat the air being supplied for the same combustion process. The heat exchanger passages are arranged counterflow and can be made integral with the burner as in the self-recuperative burner, (49).

Regenerators

Regenerators are heat exchangers in which heat is transferred between exhaust and inlet streams on a cyclic basis involving a thermal mass heat store which is warmed by waste exhaust for a period of time and then used to heat the inlet stream for a corresponding period of time.
The thermal store is usually a matrix of metal or refractory material. Clearly, in order to sustain continuous heat transfer from exhaust to inlet, two thermal stores are required which alternate between the heating and cooling phases.

Heat Wheels

A heat wheel uses the same principle as the regenerator. The wheel consists of sectors of steel mesh or inorganic fibrous materials coated with glass ceramic. Exhaust and inlet are ducted so that they run adjacent to each other and the wheel is installed so that half of its face area is in each of the two ducts. The wheel is rotated and thus moves sectors of matrix warmed in the exhaust stream to heat the inlet stream. The main area of application for heat wheels is where heat exchange between large masses of air having small temperature differences is required such as in ventilation and extraction from building spaces.

Heat Pipes

A heat pipe is a self-contained heat transport system (Section 2.7.2) which consists of a pipe lined with a metal mesh and containing a working fluid. At the hot end of the pipe the fluid evaporates and the vapour is driven along the pipe under its vapour pressure. At the cold end the vapour condenses thereby giving up its latent heat. The condense fluid then moves under capillary action in the wire mesh lining towards the hot where the mesh is dryer due to evaporation taking place. Heat pipes have not had wide scale use to date but their usefulness is their ability to transfer large quantities of heat from one point to another on a piece of industrial plant.

Heat Pumps

A heat pump is a heat engine in reverse (Section 2.7.3), that is, it takes heat from a low-grade source and supplies it for use at higher temperatures. To achieve this there has to be an input of mechanical power to bring about the upgrading of the heat.

There are two practical arrangements for a heat pump:

(a) Vapour Compression Cycle

In the vapour compression type heat pump a fluid is boiled at 'low' pressure by heat from the 'cold' source and the vapour produced is then compressed so making the saturation temperature for the condensation process at a higher temperature. The vapour is condensed at this higher temperature by transferring to the 'high' temperature sink. The working fluid then goes through a pressure reduction process in a throttling valve to return to the 'cold' source heat exchanger to complete the cycle.

(b) Absorption type

The absorption type of heat pump makes use of the ammonia - water equilibrium reaction:

$$NH_3 + H_2O \rightleftharpoons NH_4OH$$

When ammonia (NH_3) dissolves in water (H_2O) the reaction giving ammonium hydroxide (NH_4OH) is endothermic and can be used within a heat exchanger to refrigerate an air stream or other medium. Heating of ammonium hydroxide solution causes the equilibrium to reverse giving ammonia, water and also liberating the heat absorbed previously in the cycle from the refrigerated medium.

2.9.3 Alternative Fuels, Advanced Combustion Systems and the Burning of Waste

The main developments in this field have occurred with the widespread availability of natural gas since the late 1960s and early 1970s. Natural gas burns cleanly to give just carbon dioxide and water as combustion products. These attributes have led to a number of new ideas in combustion technology namely 'direct firing' and 'fully condensing' systems. Direct firing is where the flame and piece to heated are in direct contact. A fully condensing system exhausts the water from the combustion products after heat transfer as liquid and not vapour and thereby gaining the gross calorific value as opposed to only the net calorific value (Section 2.7.4). Also exhaust products in the fully condensed state are cool and flue arrangements can be handled in unconventional ways as described in the following 'new' natural gas burner types.

(1) Black Radiant Tubes

The 'black radiant tube' is the heat transfer surface of a black radiant system which emits heat basically by radiation. The tube is natural gas fired having a gas injector nozzle a one end and in induced draught fan at the other end. The tube is used to space heat tall factory buildings where radiant heat transfer to bodies in the building is a more efficient mode of transfer than attempting to warm up large volumes of air to comfort level. Radiant heating can use up to 60% less energy in producing equivalent comfort conditions to warm air heating.

(2) Imersion Tube Tank Heater

An imersion tube heater has the same arrangement as a black radiant tube but is used to heat liquid in vats and tanks. Heat transfer is conductive/convective. The imersion tube can be made fully condensing and have an overall efficiency of greater than 90%.

(3) Radiant Plaque

A radiant plaque is another radiative heat transfer system used for space heating. The radiation given off has visible red frequencies as well as the infra-red band given off by black radiant systems. The radiant plaque consists of a ceramic matrix which is direct gas fired.

(4) Catalytic Surface Combustion

Natural gas combustion can be made to take place on a catalytic surface virtually with no flame involved. Heat transfer from the reaction is effective and precise leading to low levels of waste and therefore good efficiency.

(5) Self-Recuperative Burner

The self-recuperative burner was described in Section 2.9.2 and also in reference (49).

Advanced Combustion System for Solid Fuels and Waste

An area of development in the burning of solid fuel is a technique known as fluidised bed combustion. In this type of combustion system, particles of pulverised solid fuel forming the bed are suspended in an upwards moving air flow in which combustion takes place. The benefits of fluidised bed are:

(1) Good mixing of the air and fuel enabling high heat outputs from compact combustion units.

(2) The heat flux from a fluidised bed is near uniform over its area and this makes effective use of heat transfer surfaces beyond the combustion chamber.

(3) Fluidised bed facilitates the burning of fine particulate solid fuel. Solid fuel in this form is easy to handle since it can be blown along pipes and therefore has similar convenience to oil.

(4) Fluidised bed systems can burn pelleted or pulverised waste.

2.9.4 Energy Saving Controls

Eleven types of control strategy are described in this section. Apart from the automatic on/off (timeclock) strategy the other ten arrangements are all for use on HVAC plant. Clearly there are possibilities for specialised energy control on specific items of process and production plant throughout industry but to describe these possibilities further than the general principles given in Section 2.7.6 would be difficult and virtually pointless in view of their limited range of application. Space conditioning controls, however, are applicable to virtually every building and are particularly relevant on a site like GEC Whetstone where 98% of heat raised goes to building services (Section 2.4). For this reason heating, ventilating and air conditioning control strategies are covered specially in the following descriptions. The descriptions are taken from a USA source, (50) which is interesting because the wide range of climates experienced across the USA prompts coverage of a wide range of control strategies.

(1) Automatic on/off (Timeclock Control)

Automatic on/off control can be used to make energy savings by switching plant such as heating equipment, lighting and production machines in accordance with the occupancy and working patterns.

(2) Optimum Start

The optimum start time for a HVAC system is such that the building just recovers comfort conditions for the start of occupancy. The functioning of an optimiser for computing optimum start has been described in Section 2.7.6.

(3) Temperature Setback

Use of temperature setback is an alternative to optimum start. During the non-occupancy period the building temperature thermostats are reset to a lower setting thereby reducing the energy input requirement but maintaining thermal conditions where a known period of preheat will return the building to comfort conditions.

(4) Fresh Air Shut-off

When HVAC plant is running but the building is not occupied such as the operation to recover comfort conditions or maintain a setback temperature it is not necessary to introduce fresh air for ventilation. Fresh air dampers should be fully closed with full recirculation taking place during these periods.

(5) Free Air Cooling

Internal heat loads in a building may require the HVAC system to provide cooling even though outside air temperature is cooler than the desired internal temperature. Under these conditions it is possible to take advantage of the cooler outside air by introducing it into the building to provide some or all of the necessary cooling. On an air conditioning system this means opening the fresh air dampers to relatively high volume flow rate whilst recirculation is towards the minimum.

(6) Enthalpy Control

Enthalpy control is an improvement to the basic controls for free air cooling in that it takes into account latent heat due to humidity as well as the more simple sensible heat due to air temperature alone. Levels of fresh air input and recirculation air made on the basis of enthalpy minimises the amount of heating or cooling that is necessary.

(7) Floating Supply Temperatures

Multizone, dual-duct HVAC systems consist of two parallel ducts carrying heated and chilled air. Zone controls mix air from these two streams in different proportions for each zone according to how much heating or cooling is demanded. Early controls on the heater and cooler batteries were designed to maintain the heated and cooled stream at given constant design temperatures and use whatever mixing that was required to maintain zone temperatures. The basic concept of floating supply temperature is to minimise the amount of mixing by adjusting the heated stream temperature to just meet the demand of the zone requiring the most heating and the cold stream to just meet the demand of the zone requiring the most cooling. The relaxed supply temperatures require less energy input at the heating and chilling plant.

(8) Floating Chilled Water Temperature

In order to minimise the work input to refrigerant compression between evaparator and condenser in a chiller unit, the chilled water setpoint temperature should be varied to the highest temperature which will just satisfy the cooling load.

(9) Multiple Chiller Scheduling

Multiple chiller arrangements should be operated to a merit rating to achieve optimum efficiency (i.e. the most efficient chiller takes the base load).

(10) Compensator Control

Compensator control modulates the output from a heating system as an inverse linear relationship with outside temperature in an attempt to prevent overheating beyond the desired internal temperature when outside weather is less severe than the design case. The control acts on a 3-port valve through which the heating system circuit is supplied. The flow through the valve is such that the circuit is supplied with a mix of hot water from the boiler or calorifier and portion of the return flow. The temperature of the heating circuit is therefore reduced thereby reducing its output whilst the boiler or calorifier supplies a reduced volume of hot water thereby reducing fuel consumption.

(11) Combustion Control

Electronic probes can be used to monitor the amount of oxygen that passes up a boiler stack and send a feedback signal to adjust air supply to precisely match combustion requirements.

2.9.5 Alternative Production Processes

There are a number of specialised production processes which have been developed in recent years to undertake operations such as specialised welding and metal refining particularly of semiconductor materials. One of the requirements of the processes means that there is a high intensity transfer of energy focussed onto a small area of the material being worked as will be shown in the following desciptions. Apart from meeting the production related criteria these processes are energy efficient because they minimise or even eliminate wasteful heating of, for example, large volumes of 'parent' metal in welding and crucibles etc. in metal refining.

(1) <u>Electron Beam and LASER Welding</u>

Electron beam and LASER welding involves directing a focussed beam to impinge on the joint to be welded. Melting occurs in a very narrow zone either side of the joint but can be made to penetrate 20 times the width of the zone, (21). Conventional gas or arc welding can only be used at a 2:1 depth to width ratio and so considerably less parent metal is heated with the electron beam and LASER techniques.

(2) <u>Heating by direct resistance, electromagnetic induction, arc, plasma-arc, dielectric loss or microwave absorption</u>

Direct resistance, electromagnetic induction, dielectric loss and microwave absorption use the internal properties of the material being heated to absorb energy as electric current, magnetic or electric flux, or electromagnetic radiation respectively and convert it to heat. Wasteful heating of receptacles and conveyors is minimised since these are made from materials which do not absorb the particular flux type or frequency of the power being emitted.

Arc and plasma-arc heating does involve heat transfer to the material being heated but since the arc discharge is in very close proximity to the surface of the material the thermal resistance to it is very low resulting in efficient transfer of heat from the power source.

Mechanical Removal of Water in Drying

The removal of water in a drying process by evaporation means that heat has to be supplied for sensible and, more importantly, latent heat. If mechanical removal of water is possible then only a fraction of the equivalent latent heat input is required. Mechanical drying processes include laundry mangles and spin dryers. A recent development for removing water droplets from surfaces is the 'air knife' which is a fine blast of compressed air which blows the drops from the surface.

2.10 Energy Conservation Measures Investigated and Implemented at GEC Whetstone

The energy management programme at GEC Whetstone had been in progress for 6 years prior to the author's involvement and comprehensive investigation of energy saving measures had been undertaken by both Rodriges (16) and other GEC staff before him. The greater part of the measures put forward were implemented. Capital expenditure on energy saving measures by 1979 amounted to £270000. The measures implemented are described by Rodrigues (16) and these are summarised by Tables (2.2) to (2.4) reproduced from his thesis. Tables (2.2) and (2.3) show the energy conservation measures which were implemented in relation to heating and electrical systems respectively. Table (2.4) shows measures which were investigated but did not satisfy GEC investment criteria. The tables include details of investment expenditure, projected savings and simple payback against each project.

2.11 Line Management and Workforce Involvement and Motivation

There are a number of steps a company energy manager can take to involve line management and the workforce. Involving personnel basically requires an objective or objectives to be communicated to them and then suitable motivation applied in order that they try and achieve the desired result. In energy management there prevails two ways of interesting personnel:

(1) Appealing to a person's 'better nature', through a promotional campaign, to switch things off and turn things down.

(2) Make personnel responsible and accountable for the necessary action through monitoring and targetting and reward those who are effective.

2.11.1 Promotional Campaigns

The purpose of a promotional campaign is to make the workforce aware of a company's energy saving programme and to indicate the contributions required of them such as switching off lights, closing windows and doors etc. The steps in a promotional campaign are described by Smith (20), and are as follows:

(1) Official Announcement

An official announcement should be made by senior management at the initiation of an energy saving programme. The announcement could include reasons for the company embarking on the programme, the appointment of an energy manager and how personnel will be affected.

(2) Joint Committee

A joint committee with representatives from all areas of the company's site meeting the energy manager serves to keep personnel advised of progress on the programme particularly where it may affect standards of comfort.

(3) Newsletters and Brochures

Newsletters and brochures either posted on noticeboards or handed-out to all personnel can serve to keep the workforce informed of the programme on a continued basis.

(4) Local Announcement of Energy Saving Performance

Where possible, energy facts and figures for specific areas should be made available to personnel. Posters displaying charts of energy consumption over time are useful in generating interest. The information for such charts is synonymous with monitoring and targetting which is to be described in Section 2.10.2. It is important to recognise that monitoring and targetting is a means of motivating line management but the promotional campaign is complementary in that it aids the line manager to bring about changes of behaviour in the general workforce.

(5) Theme and Logo

Development of a theme and logo to characterise an energy management programme will help gain programme recognition. An example of theme and logo is the Governments's "Save-It" campaign.

(6) Point-of-Use Labels and Posters

Point-of-Use labels and posters can be affixed in appropriate places to remind personnel to switch off equipment and lighting, close windows, report leaks of steam and compressed air, turn off hot water taps etc.

(7) Suggestion Scheme

The workforce can be asked to contribute suggestions for energy saving measures. This may be particularly valuable in specialised areas where specific personnel will have particular working knowledge of plant. The suggestion scheme should be supported by the award of a prize. Suggestions put forward in this way will probably require capital expenditure.

(8) Continued Communication

The promotional campaign efforts should be regularly renewed and updated in order to maintain the impact on the workforce.

(9) Training Courses

Training courses for plant operatives should be considered if standards of operating practise have any significant effect on energy efficiency.

2.11.2 Monitoring and Targetting

Monitoring and targetting is a management technique for control of energy use. It is similar to the preparation of financial budgets and keeping account of spending progress against the budgetted allowances. In fact, as far as an industrial manager is concerned, it is an extension and rationalisation of management accounting since budgetting and fiscal monitoring of manpower, materials, finance and sales is commonplace. With the increasing cost of energy, this too has sooner or later to become significant in the manager's accounts.

Monitoring

The component parts of a monitoring and targetting system are shown in Fig. (2.2) which is extracted from an article by Swallow, (51).

Monitoring means the systematic ongoing, regular recording of energy supplies to energy cost centres. Energy cost centres are initially identified by the energy audit (Section 2.3) and should include all major items of plant and individual buildings of area greater than, say, $1000m^2$. The energy supplies must be metered to give 'hard' data. Estimated consumptions derived from apportioning usage in some manner, for example by area, is not hard data and is of little use in monitoring and targetting because it makes energy saving trends ambiguous with happenings in the other apportioned areas.

Targetting

An energy consumption target is a value or range of values representing efficient energy utilisation for a given energy cost centre. Targets may be essentially of two types, namely those built up from calculated theoretical figures to allow for operational factors, or those calculated from existing consumption levels by statistical or empirical means.

Furthermore there are two levels of target setting as shown in Fig. (2.2) namely to maintain existing performance and secondly to improve performance. The responsibility for monitoring performance can normally lie totally with the line manager charged with a given energy cost centre. Usually no capital expenditure is involved only that correct operating procedures are observed and that attitudes and motivation of his personnel are reasonable. Improvement of existing performance usually involves capital expenditure on energy saving equipment. This will require authorisation at senior level by management who themselves have overall corporate energy targets to meet.

Represenation of Monitoring and Targetting Data

Three methods of displaying monitoring and targetting data commonly used are the consumption plot, CUSUM graph and standard error band. The basic format of each method is described in Fig. (2.3).

Monitoring and Targetting Schemes in Progress

A number of monitoring and targetting schemes have been installed in the UK since 1981 and in the USA since 1977. These are summarised in Table (2.5) which gives a brief description of energy cost centres involved, personnel held responsible and the reported benefits. The table indicates savings through monitoring and targetting of between 5% and 25% on energy consumptions valued in the range £100000 on a single site to £6M on a multi-site operation; with some examples of savings being achived with no capital expenditure except on metering equipment.

2.12 Summary of Chapter 2

The indication given in the Introduction to this thesis, based on the conclusions of Rodrigues (16), was that the author's work in monitoring and targetting for the Whetstone site was the next logical step in the already established energy management programme. This chapter has reviewed the theory and practice of energy management from the literature on the subject and has described the respective progress of the energy management programme at GEC Whetstone in the years preceeding the author's work.

The development of the programme at Whetstone has been moulded by a number of site and executive factors:

Site Factors

GEC Whetstone is a low energy intensity site as identified in Section 1.6.2. As shown further in the energy audit of Section 2.4, 98% of heating fuel and 62% of electricity are used to maintain building environments and represent an overhead which is fixed in relation to productivity of the site. Energy management, therefore, centres on buildings and building services (described summarily in Section 2.8) to which there is the relatively limited range of measures outlined in Section 2.9 and 2.10 that can be applied.

Executive Factors

The energy management programme at GEC Whetstone had been in progress for 6 years prior to the author's involvement and comprehensive investigation of energy saving measures had been undertaken by both Rodrigues (16) and other GEC staff before him. The greater part of the measures put forward were implemented. By 1979, capital expenditure on energy saving measures amounted to £270000 supported by annual savings in the region of £55000 in fuel and electricity as shown in Section 2.10.

Ongoing Work in 1979

There were two aspects to further work on the site in 1979.

(1) To replicate certain of the measures proven under Rodrigues' study on a wider scale across the site.

(2) To progress the energy management programme to new ideas.

The replication of measures which had been proven was made the responsibility of engineering staff at GEC Whetstone. For example, the responsibility for implementing the re-lamping of the whole site with high efficiency fluorescent and high pressure sodium lights became the responsibility of the Works Electrical Engineer after initial trials in just one building. Likewise, pipe lagging and building insulation became part of the civil engineering staff responsibilities.

As stated in Section 1.7, the author's contribution was expected in the second aspect to progress new ideas into the programme.

As shown in this chapter, monitoring and targetting has been a new area of investigation in UK industry with reports being published since 1981. Monitoring and targetting described in Section 2.11 purports to answer the problems found by Rodrigues (16) and described by the author in the Introduction Section 1.7, namely: "the lack of firm commitment from management at certain levels and the attitudes of certain staff in buildings" generating resistance to the use of intermittent heating strategy and consequential loss of its operational effectiveness. It was therefore the application of monitoring and targetting of heat usage that the author investigated with the aim of gaining commitment from line management primarily on the effective use of intermittent heating strategy.

<u>Note on Monitoring and Targetting of Electricity Consumption</u>

The author was aware that monitoring and targetting of electricity consumption would be a potentially useful exercise but the work could not be supported by tangible observations of abuse or records from Rodrigues work (16) as could the heating. However, the monitoring of a breakdown of electrical consumption was later installed by GEC staff although this was then apart from the author's line of work agreed in the interim with GEC to investigate monitoring and targetting of heat. Consequently electrical monitoring and targetting forms no part of the author's work.

Type of consumption	Nature of use	GJ	Fuel	Percent breakdown		Value £ 1979/80	Percent cost
Space heating	Indirect	85235	Natural gas and Heavy fuel oil	51	35	141856	19
Hot water service	Indirect	7575		5	3	12607	2
Process heat	Direct	1638		1	1	2726	-
Boiler losses	Loss	47904		29	19	79727	11
Distribution losses	Loss	23748		14	10	39524	5
TOTAL HEATING		166100		100	68	276440	37
Lighting - Offices	Indirect	9284	Electricity	16	4	60927	8
Lighting - Workshops	Indirect	5616		10	2	36855	5
Space heating	Indirect	5188		9	2	34047	5
Heating, ventilating and air conditioning	Indirect	4140		7	1	27170	4
Creep testing laboratory	Indirect	9464		17	4	62108	8
Machine tools	Direct	8166		14	3	53590	7
Production heat	Direct	1259		2	1	8262	1
Turbine testing	Direct	9174		16	4	60205	8
Air compressors	Direct	2180		4	1	14306	2
Transformer and transmission losses	Loss	2729		5	1	17910	3
TOTAL ELECTRIC		57200		100	23	375380	51
Turbine testing	Direct	22700	Gas oil		9	88800	12
TOTAL		246000			100	740620	100

Table (2.1) : BREAKDOWN OF ENERGY USE AT GEC WHETSTONE FOR 1979 / 80

	ENERGY SAVING MEASURE	INVESTMENT COST £	YEAR	PROJECTED SAVINGS £	SIMPLE PAYBACK years
1.	Roof insulation Block 3	14,500	1979	1500	9.7
2.	Site heating distribution pipework	3,782	1979	2000	1.9
3.	Rationalisation and insulation of heating distribution pipework	49,486	1979	4140	11.7
4.	Implementation of the Night Cut Off system for intermittently heating buildings	28,207	1978	20000	1.4
5.	Replacement of one inefficient oil boiler and provision of additional boiler capacity to load match site requirements thereby improving seasonal efficiency	122,831	1979	(2)	(2)
6.	Oxygen monitoring and control of boilers to improve combustion efficiency	17,570	1979	4000	4.4
6a.	Oxygen control only	9,960	1979	4000	2.5
7.	Ventilation control by fitting time clocks to extract fans	(1)		(1)	(1)
8.	Periodic maintenance, checking and re-setting of heating controls in heated buildings	no cost involved		not quantifable	-
9.	Draught proofing of buildings and installation of strip curtains in factory areas	(1)		(1)	(1)

Notes (1) Capital Expenditure was phased over a period of 3 to 4 years.

(2) Although there was no payback on this project, savings accrued from the replacement of one inefficient boiler

Table (2.2) : ENERGY SAVING MEASURES IMPLEMENTED AT GEC WHETSTONE (HEATING) Source: Rodrigues, (16)

AREA	ENERGY SAVING MEASURE	INVESTMENT COST £	YEAR	ANNUAL SAVINGS kWh	PROJECTED SAVINGS £	SIMPLE PAYBACK years
Block 73 Bays 1 + 2	Replacement of 180x400 watt MBFU with 180x250 watt HP sodium SON lamps	3500	1976	135000	1647*	2.1
Block 55 Bay 3	Replacement of 91x400 watt MBFU with 91x250 watt HP sodium SON lamps	1800	1976	69000	842	2
Block 55 Bays 1,2,3	Replacement of 222x400 watt MBFU with 221x250 watt HP sodium SON lamps	4300	1977	180000	2808	1.5
Block 56	Replacement of 222x400 watt MBFU with 222x250 watt HP sodium SON lamps	4500	1977	100000	1600	2.8
Block 13A	Replacement of 16x500 watt Tungsten lamps with 9x250 watt HP sodium SON lamps	210	1979	15000	294	0.7
Block 62, 60 + 3	Conversion of group switching of lights to individual switching of lights in offices	not available	(1976-1979)	not quantifiable	-	-
Street lighting	Replacement of 4x200 watt Tungsten with 4x55 SOX lamps	-	1979	no estimate made	-	-
Street lighting	Replacement of 10x500 watt Tungsten lamps with 10x250 watt HP sodium SON lamps	-	1978	no estimate made	-	-
Block 1,30	Replacement of 120x500 watt Tungsten lamps with 120x twin 8' fluorescent lights	5000	1978	113000	1808	2.8
Block 6	Replacement of 13x500 watt tungsten lamps with 11x twin 8' fluorescent lights	650	1979	13000	254	2.5
Toilets	Removed alternate lamps	no cost involved	1977	no estimate made	-	-

* Based on average cost of electricity in year of implementation

Table (2.3) : ENERGY SAVING MEASURES IMPLEMENTED AT GEC WHETSTONE (ELECTRICAL) Source: Rodrigues (16)

ENERGY SAVING MEASURE	INVESTMENT COST £	YEAR	PROJECTED SAVINGS £	SIMPLE PAYBACK
1. Combined Heat and Power Generation	746000	1977	140000	5.3
2. Heat recovery from boiler flue gases for space heating of Block 69	19000	1977	2433	7.8
3. Heat recovery from waste heat generated by site air compressors	* 3000	1977	838	3.6
4. Heat recovery from air conditioning plant in Block 72	2656	1979	400	6.4
5. Heat recovery from boiler flue gases for preheating boiler combustion air	*45000	1976	8000	5.6

* No firm costs were obtained. Those shown are budget estimates and include heat recovery equipment cost + cost of modifications to existing plant.

Table (2.4) : ENERGY SAVING MEASURES NOT IMPLEMENTED

Source: Rodrigues, (16)

Organisation / exercise	Size of energy cost centres	Whom made responsible	Reported benefits	Source ref.
UK				
Resinous Chemicals Limited (1983)	Major plant	Two nominated members of staff	23% of energy. No capital expenditure	(54)
Chorley Bleaching and Dyeing Co. Ltd.	Major plant	Energy manager	20% of energy	(54)
Rank Leisure Ltd.	Individual clubs and cinemas	Club and cinema managers	16% of energy	(54)
Silverton Mill, Devon	Major plant	Energy manager	7% of energy valued at £83000 for capital expenditure of £30000 on monitoring	(54)
Barclays Bank	Bank branches	Branch managers	£1M from 1000 sites, 18% of energy	(54)
Paper & Board Industry Demonstration (1981)	Mill sites	Energy manager appointed for each mill	Range 5.8% - 16.8% of energy for metering costs only	(55)
USA				
Buick Motor Div. General Motors (1977)	Departmental	Departmental line managers	16.7% of energy	(56)

Table (2.5) : REPORTED MONITORING AND TARGETTING EXERCISES

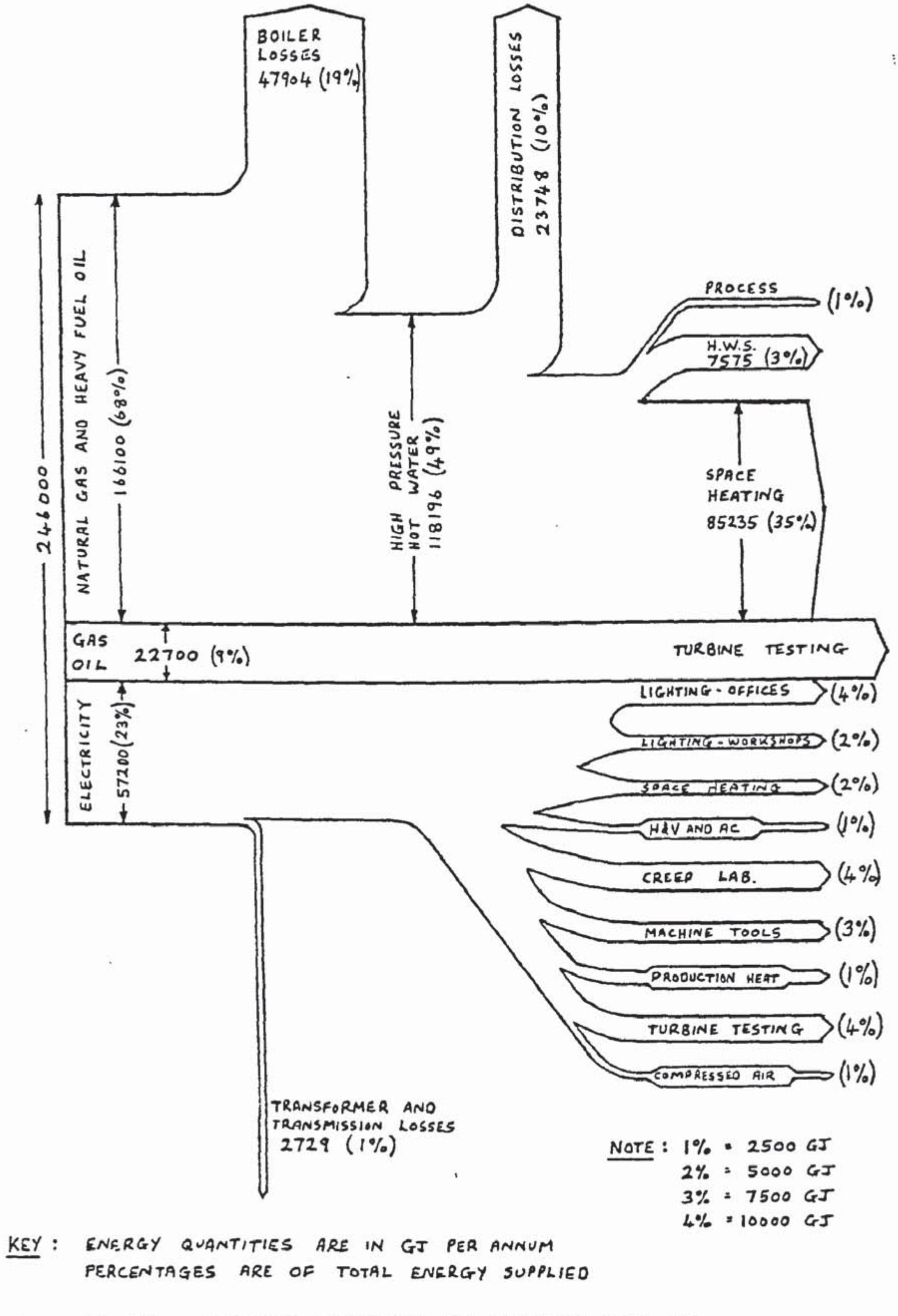


Fig.(2.1) : SANKEY DIAGRAM OF ENERGY USE AT GEC WHETSTONE

Fig.(2.2) : COMPONENT PARTS OF A MONITORING AND TARGETTING SYSTEM

Source : Swallow, (51)

Fig. (2.3) : REPRESENTATION OF MONITORING AND TARGETTING DATA

Sources : PA Management, (52)
NIFES, (53)

CHAPTER 3

HEAT METERING SYSTEM FOR GEC WHETSTONE

3.1 Introduction

Monitoring and targetting of space heating consumption in the buildings at GEC Whetstone required the specification of, firstly, the breakdown of heated area taking into account building/tenant manager divisions and, secondly, the heat metering equipment to be used.

3.2 Breakdown of Heated Area

The final solution to the breakdown of heated area was dependent on a number of factors, some of them interdependent, as follows:

(1) The different buildings on the GEC Whetstone site.

(2) The levels of line management who will be asked to participate in monitoring and targetting and the buildings they occupy.

(3) The supply of heat to the buildings:-

Supplies of heat to a building are not always conveniently arranged for metering. There are two situations where problems arise:

(a) Large buildings with a number of feeds:

Technically, there is no problem in providing more than one heat meter per building, although the internal distribution of heat may be somewhat indeterminate. However, the cost of having to provide, say, 5 heat meters to meter Block 55 when there is no justification other than that there are 5 separate feeds is 'difficult to swallow' when the economics of the project dictate a £69000 maximum expenditure. (Section 1.8.)

(b) Small buildings grouped together and heated with a common heating system:

Some small buildings grouped closely together (for example, 'Mobile' buildings 67B, 67C and 67D) are heated with a common LPHW heating system from one calorifier served by the HPHW mains. There are two heat metering options. Firstly, metering the HPHW with one heat meter and lose accuracy on individual buildings or install separate heat meters on the LPHW circuitry at increased cost.

(4) The cost of a heat meter including installation costs.

(5) The smallest heat usage which is of interest in monitoring and targetting.

(6) The accessibility of a suitable length of heating main in which to install the heat meter. Preferably this should be indoors to avoid the need for weather protection.

A level of compromise taking into account all the above six points was put forward for GEC Whetstone. The problems which made this necessary were basically two-fold:-

Firstly, areas used by line management to accommodate their production line were not necessarily convenient in terms of identifying a given building with a particular line manager. Effective use of the intermittent heating strategy at GEC Whetstone (the main reason for implementing monitoring and targetting as stated in Section 1.7) requires consideration of a building as a whole by someone who is closely associated with it, preferably, who works in it and who has recognised authority. This not always being the case, monitoring and targetting which operates through the existing line management organisation had to be slightly redressed to, for example, involve a committee formed from line management in certain buildings billed with the total heat consumption of the building. Whereas this compromises the purist's approach to accountability it is the more realistic arrangement. By continued example, foremen and supervisors (the lower rungs of line management) whose work is accommodated in the same building cannot contribute to the effective operation of intermittent heating in isolation. One forman who fails to ensure that ventilation is not closed off at the end of the day will affect the warming-up of the whole workshop the following morning. Such conditions do exist in the big workshops at GEC Whetstone in Blocks 1, 2, 55, 56, 73 and 75.

From the point of view of providing heat metering, the implication is to meter buildings as the consumption or energy cost centres. Clearly, process uses of heat should be separately metered and billed to an appropriate cost centre/line manager but as these are small on the GEC Whetstone site (1% of total heat consumption as shown on Table 2.1), heat metering on a building by building basis forms the main strategy.

The second point of compromise on the breakdown of heated area arises in the cost of heat metering. Clearly, the less expensive the heat metering system the more detailed the metered breakdown that can ultimately afforded.

The cost of a heat metering measurement is dependent on a number of factors such as type of heat meter difficulties in dealing with the heat transport medium, installation difficulties etc. and this forms the subject of the next Section 3.3.

The breakdown of heated area actually used in the heat metering system devised by the author is shown in Appendix 1. This appendix consists of 34 extracts from the 1:1250 site plan of GEC Whetstone. Each extract shows a building or buildings outlined in a thick black line which are supplied via the heat meter also shown on the plan extracts. Where two or more buildings are outlined, they are heated from the same calorifier and not individually metered because of the cost of heat metering against the relatively small consumption. Most of the small buildings in this category are mobile buildings (Portakabin, Terrapin etc.) with a fairly standard annual consumption of between 220 GJ for continuous heating and 130 GJ for well operated intermittent heating (from Rodrigues (16) work in Block 52C). The value of this heat in 1979/80 was £360 and £200 respectively. In 1979/80, in round terms, any heat meter would have cost £1000 and therefore it was impossible for such small buildings to individually give the criterion payback of 5 years in a monitoring and targetting energy saving exercise.

The tables shown in conjunction with each plan extract in Appendix 1 can be ignored at this stage. They are connected with the documentation of the heat metering actually installed at GEC Whetstone which is to be described in the following sections of this chapter.

3.3 Heat Metering Equipment

Heat metering where the transport medium is hot water is achieved by measuring flow rate in the circuit and flow and return temperatures. The heat dissipated from the circuit is calculated by:

$$q = c.m. (t_1 - t_2) \quad ..... \quad (3.1)$$

where c = the specific heat of water at the mean of t_1 and t_2. The specific heat of water is fairly constant over small temperature ranges. It is usually assumed that in a heating system the difference between t_1 and t_2 is small compared with their absolute values.

m = mass flow rate through the circuit.

t_1 = flow water temperature.

t_2 = return water temperature.

Separate measuring devices are used to measure m, t_1 and t_2. In most flow measuring systems it is volume that is measured and mass flow is inferred. It is usual in an industrial situation for all measurements to be continuously changing with time and therefore integrating computation has to be incorporated. A number of systems for making the temperature and flow measurements plus integrating have been devised.

Types of Heat Meter

Surveys of the different types of heat meter have been compliled by Singh (57), Tamm (58) and Birch (59). Singh gives the most comprehensive treatment putting forward 5 categories of heat meter.

(1) Direct multiplication type mechanical heat meters

This type of meter uses an impeller, either a positive displacement or turbine, to measure flow rate and liquid expansion thermometers to measure temperature difference. Multiplication of these measurements and integration is achieved with gearing and linkages using the impeller rotation as the power source. The meter requires no other external power supply which is an advantage if there is no electrical supply available. Heat meters of this type have been available for many years and have become known by brand names:

- Aqua-Metro heat meter
- Pegus heat meter
- Pollux heat meter
- Ferranti heat meter
- American BTU meter

The above manufacturers also make a range of other types of heat meter.

(2) <u>Direct multiplication type electrical heat meters</u>

This type of heat meter comprises a flow meter (any flow meter that can be made to give an electrical signal output) and temperature sensors to measure temperature difference which may be resistance thermometers, thermocouples or thermistors. Multiplication and integration is done by electronic circuitry.

The choice of flow meter that can be used in this type of heat meter is one of the list below. A full description of each type of flow meter is given in reference (37).

(a) <u>Positive displacement</u>
(b) <u>Turbine</u>

} Used in Aqua-Metro and Pollux electronic heat meters

(c) Orifice plate — Used in Babcock-Bristol, Fisher Controls and Kent heat meters.

(d) Venturi
(e) Pitot
(f) Vortex shedding
(g) Magnetic flow meter
(h) Doppler

} Possibilities

The choice of flowmeter is governed by the type of fluid (may be 'aggressive' or cause fouling), the magnitude of the flow, the turn-down ratio (maximum to minimum flow at specified measuring tolerance), accuracy and head loss introduced into the fluid circuit. Basically, positive displacement is accurate, 100:1 turndown, but susceptible to fouling, low flow capacity and high head loss. Turbines are accurate, 20:1 turndown, affected by fouling and aggressive fluids, medium flow capacity and low head loss. The remaining flowmeters are high capacity, less susceptible to fouling and aggressive fluids, low head loss (except the orifice plate) but only around 3:1 turndown and generally less accurate.

(3) Indirect multiplication meters

(a) Calormetro and National Coal Board heat meters

A fraction of the circuit flow rate which is proportional to the temperature difference is diverted through a water consumption meter. The proportional function is in effect a multiplication operation. The totalising read-out on the water meter provides the integrator function.

(b) BCURA heat meter

A fixed proportion of return water from the circuit is electrically heated to the same temperature as the flow. The heat consumed from the circuit is proportional to the amount of electricity supplied to heat the fixed proportion loop which is measured using a KWh meter.

The main disadvantage with indirect multiplication meters is the proportioning valve which has to work in the main flow and is susceptible to fouling and agressive fluids. Also the proportioning action of the valve is characterised by the same Bernoulli equation laws as orifice venturi and pitot based heat meters and therefore the turndown is likewise limited.

(4) Simplified multiplication heat meters

(a) Norco Junior heat meter

This heat meter is basically a direct multiplication type but has a preset flow temperature reference. Clearly if the flow water temperature cannot be guaranteed constant at the preset value there is uncertainty about the validity of heat measurement.

(b) SEGOR system of heat metering

This heat meter uses a preset flow rate making actual measurements of flow and return temperature difference only. Clearly if the flow rate cannot be guaranteed constant at the preset value or cannot be measured accurately in the first place, the heat measurement will not be accurate.

(5) Miscellaneous heat meters

These heat meters do not work on the principle described at the beginning of this section of measuring flow and temperature difference on a heating circuit. They rely on assessing heat usage at the points of emission from the heating circuit through inference with some heat driven process employed in the measuring device. Such heat meters cannot be calibrated to read directly in units of energy but have been specifically devised as low cost methods for charge apportioning in district heating schemes where the total quantity of heat produced is known. The different types of device are as follows:

(a) Thermoelectric heat meter

This heat meter uses a thermocouple loop with the hot junction on the surface of each radiator on a district heating system and the cold junction on the walls of the corresponding rooms. Each temperature difference related emf is integrated with respect to time which is periodically recorded and used to apportion heat consumed from the district heating system. The calculation to apportion heat takes the total of all time integrated emfs, makes allowances for different sizes of radiator and then divides up the total heat supplied accordingly.

(b) Topart heat meter

This meter is similar to the thermoelectric heat meter but uses resistance thermometers instead of the thermocouple loop.

(c) Evaporative heat meter

The evaporative heat meter is a simple device which is fitted onto each radiator on a district heating system. The device consists of a reservoir of special fluid which evaporates due to heat supplied from contact with the radiator. The fall in fluid level in the reservoir with time is used to apportion total heat supplied from the district heating system. Birch (59) gives an extensive description of the evaporative heat meter.

(d) Caldiv heat meter

This heat meter is similar in concept to the evaporative heat meter but uses the phenomenon of metal creep which is temperature, stress and time dependent. A constant force is applied to a metal element which then extends over time at rates dependent on the surface temperature of the radiator. The relative amounts of creep shown for all metered radiators on the district heating system is used to apportion the total heat supplied.

Other miscellaneous heat meters

Two other simple methods of apportioning heat supplied from a district heating scheme are:

(e) Hot water meter

This meter simply measures the volume of water flowing to a consumer as a method of dividing up total heat supplied by a district heating system. It takes no account of the temperature drop through a consumer circuit.

(f) Hours run meter

This meter simply records the number of hours for which a consumer draws water flow from a district system to form a basis for apportioning. Clearly no account is taken of flow quantity or temperature drop through the consumer circuit.

3.4 Development of a Heat Metering System for the GEC Whetstone Site

3.4.1 Selection of Heat Meter

A series of 'go-no go' practical considerations pointed to the necessary use of the venturi flow meter and thus the direct multiplication electrical type of heat meter. The considerations were as follows:

(1) Low cost 'miscellaneous' heat meters

The low cost 'miscellaneous' heat meters described in Section 3.2 could not be used because although the HPHW distribution system on the Whetstone site resembles a district heating scheme there is a variety of heat emitters connected to it. These include conventional radiator systems fed via a calorifier, natural convectors connected directly to HPHW, warm air unit heaters, radiant panels and air conditioning systems. Clearly, no simple 'miscellaneous' heat meter could be seen to perform fairly across this range of heat emitters, not least because they could not be installed in a functional position in some instances!.

(2) Heat meters with moving parts

The water in the HPHW distribution system is chemically treated with substances including a tannin which is added to form a lining coat on the inside of pipes to help protect against erosion from particulate matter and also self-seals small leaks such as at flanges etc. Unfortunately the tannin treatment 'gums-up' low-force moving parts such as meter impellers. Turbine flowmeters installed by Rodriges (16) had a life of about 30 months before seizing and something under a year as an accurate measuring device. Also it is not possible to use strainers before flow meters because they would clog with particulate matter like magnetite (Tamm (58)) which constantly develops in an iron piped system despite the addition of the tannin to inhibit and arrest it.

Heat meters for HPHW must have flow meters with large open bores namely the orifice plate, venturi, vortex-shedder, magnetic or Doppler types.

(3) Head loss

Orifice plate flow meters have a high net head loss (60) which is some 80% of the Bernoulli equation pressure differential produced at the tapping points. The venturi, vortex-shedder, magnetic and Doppler types have a net head loss of only 20% or less.

The HPHW distribution system at GEC Whetstone is centrally pumped, nominally 70 L/s from centrifugal pumps operating at the 45 metres head dictated by the index circuit. All other circuits were manually throttled using guess-work to achieve something approaching a system hydraulic flow balance. Some extremities of system, Block 52 in particular, exhibited symptoms of flow starvation namely under-heating and poor warm-up. GEC personnel, particularly those whose task it was to balance the system through guesswork, expressed reservation about introducing an extra 1 metre or so head loss into the less well served circuits from orifice plates. The use of heat meters employing orifice plate flow meters was therefore considered not viable.

(4) Cost

The venturi is a more simple and therefore less expensive flow meter than the vortex-shedder (typically £1800 in 1979/80) and the magnetic and Doppler types (more than £3000 in 1979/80).

Another cost related factor influencing the choice of flow meter was the commercial availability of heat meter systems using a given type of flow meter or, if no suitable commercial system was available, the relative merits of each employed in an in-house design (although cost considerations were obviously significant at the above price differentials). The next section is an assessment of commercially available heat metering systems satisfying the four flow meter related criteria described in this section.

3.4.2 Commercially Available Heat Metering Systems

The author was unable to find any commercial packages of heat meter system which employed a venturi flow meter.

Replies from some enquires where manufacturers were unable to supply venturis offered orifice plates instead. Whilst these were unacceptable as explained in Section 3.4.1, the prices were of interest. Appendix 2 shows a 'budgetary' quotation from Fisher Controls Limited for

BTU metering equipment using orifice plate flow meters. The price of £1607 per heat meter (in 1980) is budgetary, based on the average cost of orifice plate assemblies for pipework ranging from 38mm to 200mm. The quotation does not include installation costs. Taking the 34 heat metering points (Section 3.1, Appendix 1), the total equipment cost would have been in the region of 34 times £1607 equal to £54638. Bearing in mind that maximum capital expenditure on the project was £69000 (Section 1.8), the amount left to cover installation was £14362 or £422 per heat metering point. This level of expenditure on installation was found to be of the right order when the author later installed heat metering equipment at GEC Whetstone.

However, even if the price was just about acceptable using orifice plates the head loss was not as explained in Section 3.4.1. The possibility of replacing the orifice plates with venturis from another manufacturer was investigated. The only source of venturis found was from a manufacturer who primarily produced for the process and petroleum industries (Aeroquip Instruments) The cost was in the region of £3300 for a nominal 80mm or 100mm venturi. Clearly the cost of heat metering would have been twice the acceptable price with this rather specialist metering device.

Heat metering equipment using the Vortex-shedder, magnetic or Doppler flow meters was not located and anyway it was presumed that if the orifice plate based equipment was only just acceptable in price then these more sophisticated devices would be too expensive.

The conclusion drawn on the commercial availability of suitable heat metering equipment was that there was none.

3.4.3 In-house Construction of a Heat Metering System for GEC Whetstone

In view of the unsuitability of commercially available equipment it was decided that the author should investigate an in-house design and construction. Seemingly, this move would go against the cost criterion but in this case there were three foreseen advantages:

(1) The venturis could be designed to British Standard 1042 (60) and manufactured by either the General Machine Shop or Training School of GEC Gas Turbines Limited. The quality would not be 'process' or 'petroleum industry' standard but neither was the cost expected to be as high as indicated in Section 3.4.2. In fact, the eventual cost of the venturis was very low indeed, a matter of some £20 or so each since they were made during otherwise machine idle time in the General Machine Shop or in the training School at zero labour cost.

(2) The multiplication of flow and flow-return temperature difference plus integration could be detached and removed to a central processor unit thereby attempting to produce capital savings. The cost of electronics for multiplication and integration in commercial heat meters was estimated at £300 per device. This is only an estimate because manufacturers do not itemise individual component costs (see Appendix 2) and it is not always possible to identify and compare products because of the way functions are packaged, i.e. separate modules or one electronics enclosure. Based on the estimate of £300, a central processor costing equal to £10200 or less was a possibility.

(3) The multicore cabling around the site used for the night cut-off system (the system of remotely controlling motorised valves on the heating circuits from the boiler house described in Section 1.6.3) had spare cores. Utilising these spare cores for data transmission could eliminate the need for further data cabling and give capital savings on the central processor option. The multicore cabling for the night cut-off system was installed in 1976 at a cost of £20000. Most of this was labour associated with pulling-in cables to ducts, conduits etc. and therefore it was important not to incur a

similar repeat cost for data cabling but to use the spare cores and increase the viability of the central processor option.

When centralised processing of data is suggested one invokes the argument over centralised intelligence versus distributed intelligence, (Gardner (61)).

Centralised intelligence is where data is gathered by peripheral devices and transmitted to a central computer. The peripheral devices are non-intelligent and act totally under command from the central processor in terms of when and what data measurements and transfers are made. The central processor also undertakes all manipulation of data.

Distributed intelligence is where peripheral devices gather data and undertake local data processing. The role of the central processor becomes somewhat different to centralised intelligence in that can be used to monitor conditions around the system. The central processor can produce reports for the energy manager and it can be used to download new programs and parameters to the intelligent peripheral devices. Where control is being effected from such a system it is usual to have the control of individual processes to be the responsibility of an independent intelligent peripheral device. In this way the reliability of the system is improved. If one device fails the others continue to control whereas, with a centralised intelligence system, malfunction on the central computer stops the whole system from working. The disadvantage of distributed intelligence is that it is more costly than a centralised system for the same basic operating strategy, (Gardner (61)).

The parallel to a distributed intelligence system in relation to heat metering at GEC Whetstone would be to have had independent heat meters at metering points and monitor units of energy, say MJ, transferred as data from the meter readouts to a central computer. The cost of such a system would be the same as a basic heat metering system (Section 3.4.2) plus extra for the central computer facility. As stated in Section 3.4.2, this could not be afforded.

The system of centralised intelligence which the author advocated on the grounds of lower cost against reduced reliability (where, in any case, malfunction would not be catastrophic on a system which purely monitors) makes only 'raw' measurements of pressure difference (related to flow through the venturi) and flow-return temperature difference for transmission back to the central processor. All square rooting, multiplication and integration is undertaken at the central processor.

In the author's opinion, the use of a packaged central microcomputer offers the in-house producer the only viable facility for processing square roots, multiplication and integration all of which are required in a venturi based heat metering system. Complex linkaging, gearing and dedicated electronics used in commercial heat meters are out of the scope of the in-house producer if he is to compete with the same commercial products. Further, not only to compete but to make affordable a heat metering system for GEC Whetstone (i.e. costing £69000 or less in 1979/80 (Section 1.8)), the in-house producer has to look at a centralised intelligence system as shown above. Clearly the 'affordable' as opposed to the 'commercial competition' was the important factor bearing in mind the allowable level of capital expenditure.

3.5 The Experimental Phase

Having supposed the building of an in-house heat metering system it was agreed between GEC and IHD at the First Annual Review on 9 October 1980 that the author should proceed with experimentation and prove a system prototype. There were two areas where experimental trials were required.

(1) The venturi flow meter

(2) The use of the spare night cut-off cabling.

3.5.1 Design of the Venturi Flow Meter

The flow elements for the venturi flow meters were designed using BS 1042 (60). The design calculations produced in Septemter 1980 are reproduced in Appendix 3 A miniature of the engineering drawing used to specify the venturi manufacture is also given in Appendix 3.

Test to check venturi design

A check on the design of the venturis was undertaken by testing a venturi against a calibrated orifice plate in a hydraulic flow rig. The hydraulic flow rig used belonged to the Department of Mechanical Engineering at the University of Aston. It consists of a tank at 40 metres head which feeds down a 100mm internal bore pipe to the Hydraulics Laboratory where there is a manual control valve, the calibrated orifice plate with differential water manometer and flanged connection for test pieces. Water from the rig is discharged to a sump and which is pumped back to the header tank as required. A diagram of the author's test venturi is shown in Fig. (3.1).

The calibration of the orifice plate was sourced historically by comparison with a magnetic flow meter when the rig was originally built. The calibration curve was reported (62) as having been derived by fitting a

3-term polynomial to measured points of flow as determined by the magnetic flow meter and pressure difference as measured by the manometer across the orifice plate. The calibration curve so derived was given as

$$Q_c = 7.7678 \times 10^{-4} \sqrt{h_o} + 7.39 \times 10^{-5} \quad .. (3.2)$$

where Q_c = Volume flow rate in m^3/s

h_o = Differential head in cm

The coefficient of the third term in the polynomial was reported as negligible. The correlation coefficient associated with the least squares method of curve fitting was reported as 0.9999736 (where 1 would have been a co-incident fit).

This level of essentially systematic error was totally overshadowed by the random error introduced into individual readings of the manometer by fluctuations in differential pressure head due to irregularities in velocity profile. The repeatability was quoted (62) and observed by the author at $\pm$0.5% of a given differential reading. This gives rise to a $\pm$0.25% tolerance on individual flow measurements after square rooting in equation 3.2. Taking systematic error as zero (as above) and random error as $\pm$0.25%, the tolerance on individual flow measurements by the orifice plate/manometer was therefore $\pm$0.25%.

Appendix 4 shows the BS 1042 calculation of tolerance for the 2 inch test venturi. The figure calculated is ±1.77%. The calibrated orifice plate test rig at ±0.25% tolerance was therefore capable of resolving the expected inaccuracy in the test venturi.

The purpose of the test was an acceptance test to BS 1042 The objectives of the test were therefore to prove that:

(1) The instantaneous flow rate at design pressure differential was within ±1.77% of design flow rate.

(2) That the differential pressure versus flow rate characteristic in the range 71% to 100% design flow rate was a square root relationship (i.e. corresponding pressure differentials are 50% and 100% the design pressure differential) to within the ±1.77% tolerance on instantaneous measurements calculated in Appendix 4.

(3) That the net head loss across the device at design flow rate was 200mm water gauge.

The test was carried out by connecting the test venturi piece shown in Fig. (3.1) to the flow rig. The pressure differential developed by the venturi was measured with a Bourdon differential pressure gauge with a full scale deflection of 50 inches water gauge (127cm w.g.). The procedure during the test was to vary the flow rate with the control valve and set the venturi differential to values between 0 and 50 inches in steps of 5 inches water gauge and then read the water manometer measuring the differential developed across the calibrated orifice plate.

The results are shown in Table (3.1). The readings were repeated several times with no differences discernible. This is understandable since the manometer levels were subject to small fluctuations as mentioned previously and therefore hysterisis in the system is overcome although at the expense of the ±0.5% repeatability already accounted for.

The results are shown graphically in Graph (3.1) from which the following conclusions can be drawn:

(1) The pressure differential versus flow rate characteristic is within the BS 1042 standard tolerance in the range of flow from 0.96 to 1.75 litres/sec where 1.75 litres/sec is the design flow rate. This range represents a turndown of around 2:1.

(2) Subject to experimental accuracy (i.e. the tolerances on the calibrated orifice plate (±0.25%) and test

venturi (±1.77%) <u>not</u> being additive) the range for which the test venturi pressure differential versus flow rate characteristic can be said to be within the BS 1042 tolerance is extended from (1) above to the range 0.55 to 1.75 litres/sec. This range represents a turndown of just over 3:1 which is typical for a Bernoulli metering device as stated in Section 3.2.

Net head loss at design flow rate was measured during the test by connecting the Bourdon differential pressure gauge across the tapping points upstream and downstream of the venturi as shown on Fig. (3.1). The net head loss was 200mm water gauge and therefore conformed to the BS 1042 design.

3.5.2 The use of the Spare Night Cut-off Cabling

The design of a method to use the spare night cut-off cabling for data transmission from metering points to a central computer on the GEC Whetstone site had to consider:

(1) How many spare cores were available in the various lengths of multicore cable going from point to point around the site.

(2) How close were the terminations of the lengths of multicore to planned heat metering points.

(3) The signal quality of the spare cores especially bearing in mind that the other cores have potentials of 50 volts a.c. and current levels of up to 0.5A flowing. Individual cores in the multicore cabling are not screened and consequently the capacitive and inductive coupling is high and therefore induced interference is inherent.

Numbers of Spare Cores

Basically there are 3 ways of correcting cable for electronic data transmission:

(1) Hardwire each measurement from the outlying points back directly to the central computer. This requires a high number of cores to be available on the trunk routes (i.e. The route which will be followed by large numbers of individual signal cables, most notably the routes immediately connecting to the central computer). This type of connection for 34 heat meters was impossible with, virtually everywhere, there being insufficient spare cores.

(2) Parallel data transmission, (63). Each measurement is converted to a binary word and bits of that word are represented on individual cores of databus connecting to the central computer. The same databus connects a number of data input points. Specific words of data are represented for short durations of time sufficient for the central computer to receive the word which may then be followed by transmissions of other words from other data input points. The databus for parallel data transmission consists of upwards of 9 cores (24 cores for IEEE-488) and this number of cores was not generally available in spare night cut-off cabling.

(3) Serial data transmission, (63). Measurements are converted to binary words as in parallel data transmission but instead of bits being represented simultaneously over parallel lines they are transmitted sequentially on just 2 cores. The central computer operates in synchronism with the transmission of bits in order to recognise series of bits making up words of data. The 2-core serial databus can connect a number of data inputs with communication between the points and central computer taking place similarly as for parallel transmission although speeds are slower because of

the time break-up of a serial word. A 2-core network could be connected up from the spare cores in the night cut-off system multicores and so the author proceeded with the design of a serial data transmission system.

Cable Terminations relative to Heat Metering Points

The terminations (junction boxes) for the night cut-off multicore cabling were conveniently close to heat metering points. The terminations were originally arranged to connect to the motorised night cut-off valves on individual heating circuits. For practical reasons the motorised valves had been installed in serviceable locations such as plant rooms and the same physical access to pipework made the same locations attractive for the installation of the heat meters.

Signal Quality of Spare Cabling

The level of interference induced onto the spare night cut-off cores by the 50 volt 0.5A flowing in adjacent cores of the multicore was quantified by a simple test. The test involved connecting an oscilloscope to a pair of spare cores contained in the longest signalling distance on the GEC Whetstone site. Details of the test were shown in Fig. (3.2). The oscilloscope showed a sinusoidal waveform with frequency of 50 Hz (mains frequency) and amplitude of between 3 and 5 volts related to the number of night cut-off control cores energised at any one time. This level of interference was too high for standard commercial interfaces to be used. These typically use ±5 or ±12 volts to energise the communications bus but have threshold sensitivities for recognising data bits as low as ±3 volts, Macari, (64).

3.6 The Design Phase

Following on from the specification of requirements for a heat metering system at GEC Whetstone in Sections 3.2 and 3.4 and the experimentation described in Section 3.5 into the design of the venturi flow meter and use of spare night cut-off cabling, the author embarked upon final design of the system.

Basically there were three levels of design activity:

(1) System Integration - The putting together of central processor, spare night cut-off cabling, data gathering outstations, flow meters and temperature sensors on flow and return pipes to heating circuits.

(2) Detailed Design - of the components which could not be purchased from commercial sources for reasons given in Sections 3.4 and 3.5.

(a) Interface devices to transfer data via the night cut off cabling.

(b) Venturi flow meter already described in Section 3.5.1 and Appendix 3.

(3) Software - to run the system.

3.6.1 System Integration

System integration is the putting together of the basic building blocks for heat metering and central processing of data as identified in the studies described in the preceeding sections of this chapter, namely:

(1) Micro-computer for undertaking the central processing.

(2) Spare night cut-off cabling.

(3) Interface device between the micro-computer and night cut-off cabling.

(4) Interface device between the night cut-off cabling and the data to be gathered at the various points around the site.

(5) Venturi flow meter and associated differential pressure transducer.

(6) Temperature sensors on flow and return pipes to heating circuits.

The basic system architecture for these building blocks is shown in Fig. (3.3)

3.6.2 Detailed Design of Interfaces for Data Communication

For the reasons given in Section 3.5.2, data communication via the spare night cut-off cabling was 2-wire serial data transmission. The various requirements for this to be undertaken are described in the Post Office Handbook of Data Communications (63) and these are:

(1) a communications protocol consisting of a description of the signal waveform and synchronisation of transmitter and receiver to the signal, and

(2) error control to suppress the effects of noise on data transmission.

The demonstration of poor signal quality of the spare night cut-off cabling described in Section 3.5.2 led the author to design a slow speed, high amplitude data signalling system. Voltage amplitudes at the central processor signal wire driving unit were made ±20 volts (+20 volts to represent binary 1 and -20 volts to represent binary 0). Threshold sensitivities at the data gathering outstations were put at a minimum of 10 volts with guaranteed response at 12 volts amplitude. (i.e. Data gathering outstations would be guaranteed not to respond to signals of less than 10 volts and guaranteed to respond to signals greater than 12 volts.) The 10 volt threshold sensitivity masks all noise at between 3 and 5 volts measured in the test described in Section 3.5.2.

To further make data recognition more reliable, data synchronisation was achieved using the return-to-zero technique. In this method, + voltages represent binary 1, - voltages represent binary 0 and 0 volts (actually -10 to +10 volts) represent an idle state. Every bit of data therefore has its leading edge to act as an independent synchronisation mark between transmitter and receiver and, when using 'dirty' cabling, serves to increase data reliability (c.f. the TELEX system, (63)).

Data transmission in the GEC Whetstone heat metering system occurs at the dictates of the software in the central processor such that when a given measurement of flow or temperature difference is required a polling routine is invoked to acquire the value.

Polling Routine

The polling routine consists of sending an 8-bit digital address sequence followed by an 8-bit interrogation sequence. The waveform of a typical polling sequence is shown in Fig. (3.4). The address sequence consists of a transmission by the central processor of +ve and -ve data pulse which are recognised by data gathering outstations. The address selects one particular input to the data gathering outstations. During the interrogation phase the central processor transmits a series of 8 +ve pulses and the digital value of the input is returned semi-passively as high and low current conditions in the signal cabling. Low current (less than 150 mA) represents binary 0 and high current (greater than 250 mA) represents binary 1.

Error Control

Error control was implemented using a procedure whereby up to 10 readings of a respective input are made on a repeated basis until 2 consecutive measurements agree to within plus or minus the least significant bit. This is a slow method as at best it is double the basic data transfer time but the advantage is that it checks data acquisition inclusively from the point of sensing through to the central processor. It also introduces a 'smoothing' into particularly flow measurement which may be transitory high or low due to valves opening and closing and pumps being switched on and off.

Polling routine and error control are generated in software and a flow chart of the steps involved is shown in Fig. (3.5). The line references given in the figure refer to the software listing, Fig. (3.22).

Signal Wire Driving Unit

The signal wire driving unit is the interface between the central processor and the signal wire pair. Its function is to translate the low power logic states used in the micro-computer into the higher powered signals on the transmission wires and visa-versa.

The conversion between 8-bit parallel information and serial communication is a function of the polling sub-routine. The signal wire driving unit is purely an amplifying device which operates to instructions from the polling routine. There are four operating states under control from the processor unit.

(1) Transmit zero volts

(2) Transmit negative 20 volts

(3) Transmit positive 20 volts

(4). Transmit positive 20 volts and monitor current flowing in the signal wire pair.

The circuit diagram of the signal wire driving unit is shown in Fig. (3.6) and its component list in Fig. (3.7). Fundamentally the circuit consists of two power supplies which are electronically switched to enable energisation of the signal wire pair with zero, positive 20 volts or negative 20 volts. The positive voltage power supply has a current measuring facility in circuit to achieve state (4) operation which is used during the interrogation phase of the polling routine.

Data Gathering Unit

A data gathering unit is an outstation data handling device to interface sensors to data transmission on the signal calling. Basically the functions are to translate the signals from the flow and temperature difference measurements into the digital sequences of high and low currents answering to the interrogation phase following a recognised polling address.

A block diagram illustration of circuits within a data gathering unit is shown in Fig. (3.8). The heart of the unit consists of two shift registers for parallel-serial data conversion and an analogue-to digital converter which digitises the measurements being made.

Address sequences are fed via the front end circuitry, shown in Fig. (3.9) , into the address recognition shift register. The function of the front end is to translate the high power, positive and negative signals on the transmission wires into noise free binary states for logic circuitry. Address recognition circuitry is shown in Fig. (3.10) and consists of the shift register (IC3 and IC4) with direct outputs and their inverses (IC5) available for connection via the ADDRESS SET switches to an AND-gate enabling function (IC6). The integrated circuit timer (IC2) delays the clocking of the shift register for 0.001 seconds after the reception of the leading edge of a bit in order that loading state is established.

Data gathering units were designed to accommodate four or eight measuring inputs. A heat metering point uses a pair of inputs, one for flow and one for flow-return temperature difference. Accommodating four inputs in one unit economises on components. Further economies result where two or more heat metering facilities are fed into an 8-input unit. In the 4-input units, the two least significant bits of the address recognition shift register are used to operate the input selector (IC11 shown in Fig. (3.12)). An 8-input unit has the three least significant bits routed to its selector.

On completion of the address sequence, analogue-to-digital conversion of the selected input takes place. The 8-bit measurement is then loaded into the second shift register contained in the parallel-to-serial data conversion circuitry. The data is clocked from this shift register in response to interrogation pulses. The binary states of the data switch a power device in the front end circuitry (IC1 shown in Fig. (3.9)). This causes the high and low current conditions on the transmission wires. The circuits for parallel-to-serial data conversion and analogue-to-digital conversion are shown in Figs. (3.11) and (3.12) respectively.

If a fault occurs during a polling sequence all circuits are automatically reset. The circuitry for undertaking this is shown in Fig. (3.13) and consists of a timing device which causes reset one second after any transmission wire energisation. A polling sequence is undertaken in less than half the reset period.

Auxiliary circuits within a data gathering unit are a clock for the analogue-to-digital converter (Fig. (3.13)) and the power supply (Fig. (3.14)).

The component list for one data gathering unit is shown in Fig. (3.15). This list does not include components for the operational amplifiers which amplify the millivolt or microvolt signals from the transducers to voltages compatible with the 2.55 volt full scale sensitivity at selector inputs. The operational amplifier circuits are shown in Figs. (3.16) and (3.17) and their component lists appear on Fig. (3.18). The standard operational amplifier is used to couple to the single-ended inouts of thermocouples. The differential operational amplifier is used to connect to the bridge measuring networks of the differential pressure transducers on venturi flow meters.

Flow-Return Temperature Difference Thermocouples

There are 3 types of sensor for electrical temperature measurement namely platinum resistance, thermocouple and carbon thermistor. The advantages and disadvantages of each in the use of measuring temperature difference (i.e. measurement of 2 temperatures and subtracting) are as follows:

(1) Platinum Resistance

Platinum resistance temperature sensors to BS 1904 (65) are generally taken as the standard for electrical temperature measurement. Sensors conforming to BS 1904 are closely enough matched to enable temperature difference to be measured using a bridge circuit and differential input to the indicating device. The resistance/temperature characteristic is 0.385 ohms/^{o}C on a BS 1904 standard, 100 ohm at 0^{o}C, sensor which would enable a 0.25^{o}C resolution in a 60^{o}C temperature difference with 8-bit digitising.

Note: A temperature difference of 60^{o}C is twice the design flow-return temperature difference for the HPHW system at GEC Whetstone and was taken as a practical value for specifying instrumentation.

(2) Thermocouples

Thermocouples to BS 4937 (66) for measuring temperature difference are simple devices since the 'hot' and 'cold' junctions at each of the two temperatures results in an emf proportional to the difference. Such thermocouples can be made for a few pence from thermocouple wire. Whilst thermoelectric effect is a reliable means of generating an electrical measurement it does not produce a very high signal source (typically 40µV/^{o}C from a copper-constantan junction). Consequently, instrument gains have to be high and thus become susceptible to other sources of interference if precautions are not taken to eliminate them.

(3) Carbon Thermistor

Carbon thermistors are basically inexpensive and give a large signal relative to temperature variation. However, for temperature difference measurement, close tolerance or matched thermistors have to be used and this increases their cost. Also thermistors have negative temperature coefficients which complicates the bridge network and the computation of temperature difference values.

For measurement of temperature difference in heat metering at GEC Whetstone, thermocouples were used because of their low cost and simple circuitry. Further to reduce costs, the thermocouples were surface mounted. Whilst it is considered generally that this method of mounting is not as accurate as an imersion pocket, the discrepancy introduced in measurement on a pipe at 150°C with nominal covering of pipe insulation is about -1°C on absolute values, Comark Company (67). The discrepancy on measurement of temperature difference where HPHW flow temperature is 160°C, return at 130°C and ambient at 20°C is estimated from Comark data (67) at -0.23°C. In practice it is doubtful whether imersion pocket temperature measurement would better this because heat conduction along the pocket has similar effect to surface heat loss at surface mounted sensors.

Measures had to be taken to suppress electrical interference to the thermocouples which can be picked-up in two ways. Firstly, the HPHW pipework forms a 'loop' which runs around the site through most buildings. Interference is transmitted from the many sources on the site to where thermocouple junctions are in contact with the pipe. The elimination of this source of interference was achieved by both earth bonding flow, return, electrical mains earth and electronics earth and by electrically insulating the thermocouple junctions from pipework with mica sheet. The second source of interference pick-up is due to the thermocouple cables themselves passing through interference fields of electrical equipment. Electric motors powering heating system circulating pumps produce considerable interference fields within plant rooms. Elimination of this source of interference was achieved by electrically screening the thermocouple cables with flexible metal conduit.

Venturi Flow Meter

The design of the venturi flow meter has already been described in Section 3.5.1 and Appendix 3.

The pressure differential across the venturi is measured by a standard semiconductor type differential pressure transducer manufactured by Druck Limited of Leicester, Type PDCR 120/WL.

3.6.3 Software

The software in the central processor has to perform two general functions namely:

(1) Measure heat consumptions

(2) Record these heat consumptions and periodically report the readings to management.

Measurement of heat was discussed in Section 3.3 and is described basically by the following equations:

$$q = c.m.\,\Delta t \quad .... \quad (3.1)$$

where q = instantaneous heat flow rate

c = specific heat of water

Δt = flow-return temperature difference

m = mass flow rate of water in the heating circuit

A venturi is used to measure m, therefore

$$m = M\sqrt{\frac{h}{H}} \quad ..... \quad (3.3)$$

where M = design flow rate of the venturi in terms of mass flow rate

H = differential pressure developed across the venturi at design flow rate

h = instantaneous differential pressure reading

Finally heat consumption is obtained by integration of the instantaneous heat flow rate, q, with respect to time.

$$Q = \int_{t_{i-1}}^{t_i} q(t).\, dt \qquad .... (3.4)$$

where Q = heat consumption of time period t_{i-1} to t_i

q(t) = heat flow rate as a function of time

Obtaining heat flow rate as a function of time imposes a consideration concerning the accuracy of the heat metering system. Ideally the function should be continuous; that is temperature difference and flow rate should be continuously monitored, multiplied and integrated. In any system of remote data logging involving polling for data (refer to Section 3.6.2) the function q(t) has to be constructed from discrete valued sample data. Accuracy can be impaired since variations having a high frequency than the sampling frequency will not be fully accounted for.

Rodrigues (16) in his work involving heat meters states that the choice of sampling period in a practical situation can only be made by trial and error. The author made use of Rodrigues limited heat metering in 4 buildings (described in Sections 1.7 and 3.4.1) to select the sampling period for the site heat metering system.

The heat meters used by Rodrigues sampled every 30 minutes. In his analysis of errors he reduced the sampling period to 10 minutes and reports in his thesis (16) that no significant change in accuracy could be observed. He also makes reference to the work by Singh (57) who made a detailed assessment of sampling errors in heat metering and concluded that over a complete heating season, sampling at 30 minute intervals would introduce negligible error basically because of cancelling effects.

Based on the above information the author decided on a sampling period of 10 minutes or less would be satisfactory. In the software program developed by the author the sampling period is in fact variable depending on how many data errors are encountered. The minimum cycle time for sampling each of the 34 heat metering points is 170 seconds. If data errors are encountered this time is increased because more measurements are made under the error control procedure described in Section 3.6.2.

The error control procedure in addition to eliminating data errors also inherently increases measuring accuracy because, as stated in Section 3.6.2, it requires two consecutive measurements to agree to plus or minus the least significant bit before accepting the measurement. This therefore acts as a filter for transient phenomenon ensuring that only stable values are used for the computation of heat consumption.

Returning to the discussion of the heat metering equations, it is clear that each of the 34 heat metering points has different parameters, for example different sized venturis and different zero positions on pressure transducers. These need to be incorporated into the equations. Therefore combining equations 3.1, 3,3 and 3.4 and inserting factors and offsets to measured variables the following equation is produced.

$$Q = \int_{t_{i-1}}^{t_i} c.(A.\Delta t+B).M \sqrt{\frac{(C.h-D)}{H}}.\ dt \quad \ldots (3.5)$$

where: A = Temperature differential gain

B = Temperature differential zeroing offset

= zero because zeroed at the operational amplifier

C = Pressure transducer conversion factor and gain

D = Differential pressure offset

M also a parameter dependent on the size of the venturi

The software program for the heat metering system was therefore written to fundamentally operate equation 3.5 for each heat metering point using measurements polled from data gathering unit around the site and stored values of A, B, C, D and M. A full list of functions is as follows:

(1) Poll ('dial-up') the required temperature difference and pressure differential (flow) measurements.

(2) Access appropriate values of A, B, C, D, and M from storage within the central processor.

(3) Remember time t_{i-1} and know time t_i from the internal clock.

(4) Trapezoidally integrate to approximate the ideal integration of equation 3.5.

(5) Cumulate and store the resultant heat consumption value.

(6) Cycle through all 34 heat metering points.

(7) Produce a print-out of cumulated heat consumptions for heat metering points when requested to report to management.

Flow charts of the software giving more details are shown in Figs. (3.19) - (3.21). A listing of the program which was written in BASIC by the author is shown in Fig. (3.22).

An illustration of the print-out of heat consumptions is illustrated in Fig. (3.23). A specimen full print-out is given in Appendix 5. Print-outs are obtained on request at the central processor and give the current values of cumulated heat consumptions since figures were last reset to zero in the program.

The store of constants A, B, C, D and M is illustrated in Fig. (3.24): MATRIX OF DATA FOR GEC WHETSTONE HEAT METERING. A full listing of values is given in Appendix 6 and a precise description of each column of numbers appears in Appendix 7.

The MATRIX OF DATA FOR GEC WHETSTONE HEAT METERING was prepared using a separate data loading program. A flow chart of this program is shown in Fig. (3.25) and the program listing is displayed in Fig. (3.26).

3.7 The Installation Phase

3.7.1 Central Processor

The central processor was assembled from Commodore Business Machines equipment consisting of the following:

- Commodore 3032 32K microcomputer with integral VDU and keyboard
- Commodore 3022 Printer
- Two tape cassette decks
- Signal wire driving unit described in Section 3.6.2

A photograph of the equipment is shown in Fig. (3.27).

3.7.2 Data Gathering Outstations

The activities to install a data gathering outstation are shown by the path diagram in Fig. (3.28). During the installation of the 34 heat metering points at GEC Whetstone the author had day-to-day responsibility for directing the installation activities. A brief description of the activities are as follows: (Activity reference numbers are according to Fig. (3.28)).

Activity 0 - 1 : Manufacture of Venturis

Venturis were manufactured by centre lathe turning undertaken either in the Training School or General Machine Shop of GEC Gas Turbines Limited. The machining details are given in Appendix 3.

Activity 1 - 2 : Installation of Venturis

The installation of venturis involved fabrication of a flow measuring length and then installing it at the appropriate point on the HPHW system at GEC Whetstone The work was undertaken by pipe-fitter labour employed by GEC.

Fabrication of a flow measuring length involved welding the venturi to the minimum upstream length of straight pipe specified by BS 1042 (see Appendix 3) and making flange and pressure tapping connections.

Installation of the flow measuring lengths was a continuation of the fabrication process. Installations were different in all cases but basically involved isolating the circuit, draining-down, cutting and welding flanges to accommodate the measuring length and then reinstating the circuit. An instruction sheet for fabrication and installation of a particular flow measuring point is shown in Fig. (3.29) to illustrate a typical case. The sheet had a standard format and was completed with appropriate sketches and details.

Activity 2 - 3 : Fitting of the Differential Pressure Transducer

Fitting of the differential pressure transducer with associated bypass valve, bleeds and heat dissipating copper tube was undertaken by pipe-fitter labour. The bypass valve was fitted between 'T' pieces screwed into the pressure tapping isolating valves on the venturi. The pressure transducer with air bleed facilities was mounted nearby, communicating with the pressure tappings via small bore copper tubing.

Activity 3 - 8 : Priming the Pressure Transducer

The transducer system was primed in order to remove all air and thus ensure consistent pressure readings. The task was undertaken by a technician and involved forcing water around the transducer system via the bleed openings. After priming the bleed openings were closed-off. The transducer system was not made operational until commissioning of the complete data gathering sub-system was undertaken. Pressure tappings remained isolated and the bypass valve was left open.

Activity 0 - 4 : Manufacture of Data Gathering Units

Printed circuit board preparation and assembly of data gathering units was undertaken by a sub-contracted company, System 2000 of Leicester. The artwork for the printed circuit boards was prepared by the author from the theoretical circuit diagram given in Figs. (3.8) - (3.18).

Activities 4 - 5 and 5 - 6 : Electrical Work

Electrical work involved mounting the data gathering unit enclosure, providing mains power, connecting the signal wire pair and installation of thermocouples. The work was undertaken by electricians employed by GEC.

The installation of the thermocouples entailed firstly fitting the screening metal conduits and earth bonding between each of the flow pipe and return pipe to the enclosure. The conduits were fitted to the enclosure using conduit glands. The other ends were clamped to the pipes using jubilee clips which also carried earth clamp saddles for earth bonding the pipework. Earth bonding was run from the earth clamps up each conduit to a single central earthing point to which mains earth and electronics earth were also connected. The thermocouple was then drawn into the conduit and junctions were clamped onto the pipes in a sandwich of mica sheet and asbestos tape. Silicone grease was applied to both sides of the mica sheet to ensure effective thermal conduction from pipe to the thermocouple junction.

All other activities : Commissioning

All remaining activities shown in Fig. (3.28) are commissioning for a heat metering point. Detailed commissioning instructions are given in Appendix (7).

3.7.3 Photographs of Heat Metering Point Installations

Photographs of two typical installations of heat metering points are displayed in Figs. (3.30) and (3.31). The first shows the installation in Block 56, Bay 7 and the second is in Block 69 plant room where two heat meters (metering Block 69 and Blocks 67B/67C/67D respectively) are served from one data gathering units with additional inputs (refer to Fig. (3.12); 8-input version).

3.8 Accuracy of the Heat Metering System

3.8.1 Estimated Accuracy of Individual Heat Metering Points

A basis for estimating the accuracy of heat meters is given by Tamm (58). The quantity of heat measured by a heat meter is subject to 3 sources of error:

(1) The mass flow measurement (Error e_1)

(2) The temoerature differential measurement (Error e_2)

(3) The computation and integration (Error e_3)

In the heat metering system devised by the author at GEC Whetstone, these errors physically arise for two reasons (after Singh (57)) :

(a) Quantisation : The tolerance on measurements of flow and temperature difference and digital approximation in computation.

(b) Sampling : Fluctuation in the flow and temperature difference occurring at a higher frequency that the sampling rate and the follow-on loss of accuracy during integration.

The errors can be resolved into two terms known as calibration error and random error.

Calibration Error

Calibration error can be plus or minus, but as the term implies, the error remains either plus or minus and at a given magnitude from the time of calibration. In the heat metering system at GEC Whetstone, sources of calibration error arise in the setting-up of thermocouples for measuring flow-return temperature difference and dimensional tolerances introduced in the manufacture of venturis.

The calibration error for thermocouples is estimated at 0.23°C for the range of temperature differential (Section 3.6.2). The tolerance on flow measured by the venturi is given in Section 3.5.1 and Appendix 4 as 1.77% relative to measured flow for a range of 2:1 turndown. In order to know the effects of these errors on the measured heat value it is necessary to estimate the average flow and temperature differential (Tamm (58)).

The design of the HPHW system of GEC Whetstone caters for a bulk circulation of water around the mains passing through 'diverting' valves which control heat input to building circuits. When the building requires less heat the valve passes water directly to the return and when the building requires more heat more water is diverted to the building heating system. (The reason for this type of control is that 'dead legs' on the system are eliminated.) The flow rates under such control vary only between 70% and 100% (observed from the working heat metering system) which is well within the 2:1 turndown conditions for 1.77% tolerance. Temperature differentials on the HPHW system vary between a design of 28^{o}C and 0^{o}C depending on heat load. Approximating the flow rate to a constant (above) gives an estimated average temperature differential of :

$$28^{o}C \times \frac{1}{1.3} \times 0.6 = 13^{o}C$$

where 28^{o}C is the design temperature difference.

1.3 is the heating system oversizing factor for cold start (CIBS Guide (35))

0.6 heating season diversity on space heating requirements (CIBS Guide (35)).

The error in measured heat due to temperature differential error is therefore :

$$\frac{0.23^{o}C}{13^{o}C} = 1.77\%$$

Random Error

Random error is the further tolerance in each sample heat measurement which is not attributable to calibration error. At each sampling random error can be plus or minus and vary in magnitude. Over a large number of samplings random error cancels out and therefore leaves only calibration errors between the measured value and actual value. Sources of random error in the GEC Whetstone heat metering are :

(i) <u>Hysterisis in the differential pressure transducer on the venturi</u>

From the manufacturer's data, the combined non-linearity and hysterisis affects are ±0.1% of pressure differential reading.

(ii) <u>Analogue to digital conversion of flow (pressure differential) and temperature difference</u>

In each sampling there are 2 analogue to digital conversions of flow and temperature difference followed by digital processing all undertaken at 8-bit resolution. The basic error at the least significant bit of 8-bit resolution is ±0.4%. Assuming that in practice the most likely error which occurs is that given by the root sum squared of the three error inputs (Tamm (58)).

$$\pm\sqrt{(0.4)^2 + (0.4)^2 + (0.4)^2} = \pm 0.7\% \text{ full scale heat rate}$$

(iii) Timing of samplings relative to transient changes in flow rate and temperature difference

From observations of the working heat metering system, the profiles of daily heat flow were as follows :

At initial switching-on of the heating system in a given building using night cut-off, the heat flow rate immediately goes from zero to an initial maximum whilst the heating system and building warm up. After this the heat rate drops to a controlled level depending on prevailing weather conditions which, for the majority of days, means that heat rate stays moderately constant. At switching-off the heat rate drops to zero in the closing time for the motorised valve (about 10 seconds).

Errors introduced during the rises and falls in heat rate will randomly cancel each other and over a heating season of typically 200 days there will be negligible error, Singh (57). The worst effects of errors from this source are in daily readings where heat is turned on just after a sampling and off again at the end of the day just prior to a sampling. Assuming that the heat rate throughout the occupancy period is constant and therefore no error, the measured heat will be incorrect by an amount equal to maximum heat rate multiplied by 170 seconds (the sampling period (Section 3.6.3)). Over a 10 hour heating period this represents:

$$\frac{-170 \text{ secs.}}{10 \text{ hours} \times 3600} \times 100 = -0.47\% \text{ of full scale heat quantity}$$

or assuming an average heat quantity reduced by a plant oversizing factor of 1/1.3 and a heat load diversity of 0.6, the error on measured heat quantity is about -1%. A similar occurrence could occur with sampling just prior to switch-on and 170 seconds after switch-off in which case the error would be +1%. The error is therefore ±1%.

(iv) Trapezoidal integration between heat flow rate samplings

The heat flow rates observed from the heat metering system stayed moderately constant throughout daily heating periods once the buildings were up to temperature. Random cancelling of trapezoided integration error over the 200 or so samplings undertaken during heating periods makes these errors two orders of magnitude less significant than the transient errors under Item (iii) and therefore negligible. The worst trapezoidal integration errors occur at switch-on and switch-off and these are already taken into account in item (iii).

Total Likely Error

Over an annual heating season, assuming random errors to cancel completely, the total likely error relative to the measured quantity of heat through a given heat meter is given by the root sum squared (Tamm (58)) of just the calibration errors, i.e. :

$$\pm \sqrt{(1.77\%)^2 + (1.77\%)^2} = \pm 2.5\%$$

The error in daily heat quantities is larger than ±2.5% because random error introduced at transient charges relative to sample timings becomes significant because there are too few random events. The total likely error in daily heat quantity becomes:

$$\pm \sqrt{(1.77\%)^2 + (1.77\%)^2 + \underset{(1\ \text{occurrence})}{\underline{(1\%)^2}}} = \pm 2.7\%$$

3.8.2 Overall Heat Balance for the Metering System

The author attempted to reconcile the overall summation of the heat meters with total heat produced by the boiler house measured by a master heat meter and also with gas supplied to the boiler plant. The author obtained some limited data from the site for the period of October and November 1984. This was sometime after completion of work on site. The author in fact left the employment of GEC in January 1983 after installation of the heat metering system as is explained in the following Section 4.1.

The data and reconciliation is shown on Table (3.2) as follows:

(1) Gas consumption by the boiler plant for each of the months October and November 1984.

(2) Total heat output from the boiler house as measured by a separate master heat meter (Kent Instruments device with orifice plate flowmeter and platinum resistance thermometers).

(3) Summated heat meter readings from the heat metering system print-out.

Unfortunately it is not possible to conclusively reconcile the measurements because there is an unmetered heat quantity in the form of distribution losses. Also the master heat meter is subject to the same order of error as individual heat meters. However, taking an estimate of distribution losses from the energy audit data shown in Table (2.1) does enable an approximate check on the heat metering system. The discrepancies shown in Table (3.2) are -4.5% for October 1984 and -1.5% for November. Clearly these two figures neither support nor confute the errors calculated in Section 3.8.1. One would hope that -4.5% for October is not representative as this suggests that it would be difficult to judge a 5% to 10% heat saving expected from monitoring and targetting for line management.

Differential head developed by test venturi, h_v	Calculated flow rate in test venturi, Q_v (1).		Differential head developed by calibrated orifice plate, h_o	Calibrated flow, Q_c (2).	Percentage discrepancy (3).
ins. w.g.	lb/h	$10^{-3}m^3/s$	cm w.g.	$10^{-3}m^3/s$	%
0	0	0.0	0.0		
5	4402	0.5544	0.4	0.5652	+1.9
10	6225	0.7842	0.8	0.7687	-2.0
15	7624	0.9605	1.3	0.9596	-0.1
20	8804	1.1091	1.8	1.1161	+0.6
25	9842	1.2400	2.2	1.2261	-1.1
30	10782	1.3583	2.7	1.3503	-0.6
35	11646	1.4672	3.2	1.4634	-0.3
40	12450	1.5685	3.7	1.5681	0.0
45	13206	1.6636	4.2	1.6658	+0.1
50	13920	1.7536	4.7	1.7579	+0.2

Notes : (1) $Q_v = 9842\sqrt{\frac{h_v}{25}}$ from Appendix 3.

(2) $Q_c = 7.7678 \times 10^{-4}\sqrt{h_o} + 7.39 \times 10^{-5}$

ie. Equation (3.2)

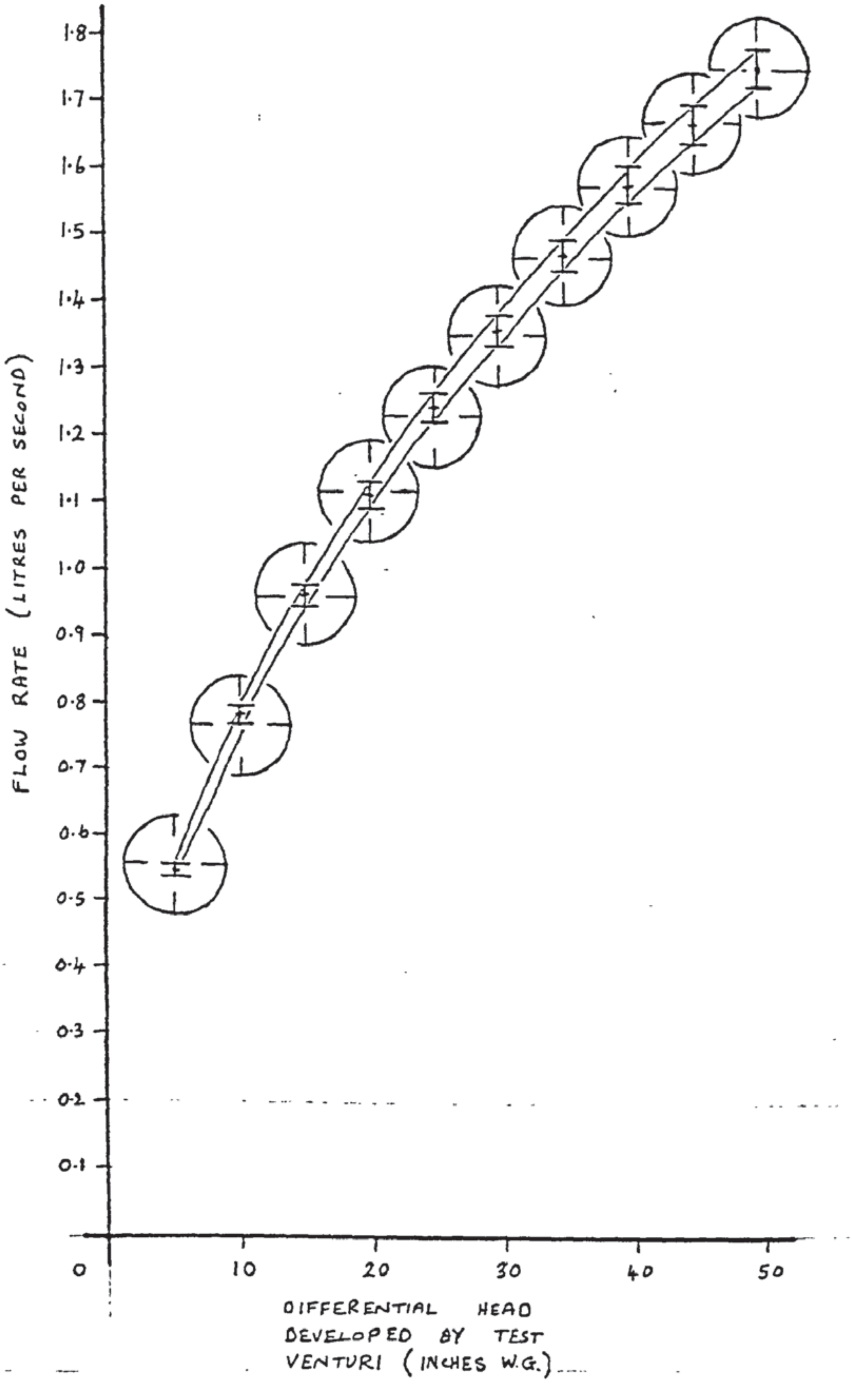
(3) Percentage discrepancy = $\frac{(Q_c - Q_v) \times 100}{Q_c}$

Table (3.1) : RESULTS OF VENTURI TEST

Month		Interruptible tariff gas meter	Boiler house master heat meter	Building heat meters	Assumed distribution losses (1).	Percentage discrepancy	Note : Boiler efficiency $\left[\frac{\text{Master heat meter}}{\text{Gas meter}}\right]$
October 1984	Therms	117630	90260	68429	18757	-4.5%	77%
	GJ	12411	9523	7220	1979		
November 1984	Therms	171630	139880	119316	18757	-1.5%	81%
	GJ	18109	14759	12589	1979		

Note : (1) - Assumed distribution losses per month = $\frac{23748 \text{ GJ}}{12}$ from Table (2.1).

Table (3.2) : RECONCILIATION OF THE HEAT METERING SYSTEM WITH GAS AND BOILER HOUSE MASTER HEAT METERS



KEY : Tolerance bars on test venturi charateristic according to BS 1042

Tolerance limits of BS 1042 characteristic

Calibration point (Tolerance approximately represented by twice the thickness of the marker lines)

Graph (3.1) : RESULTS OF VENTURI ACCEPTANCE TEST

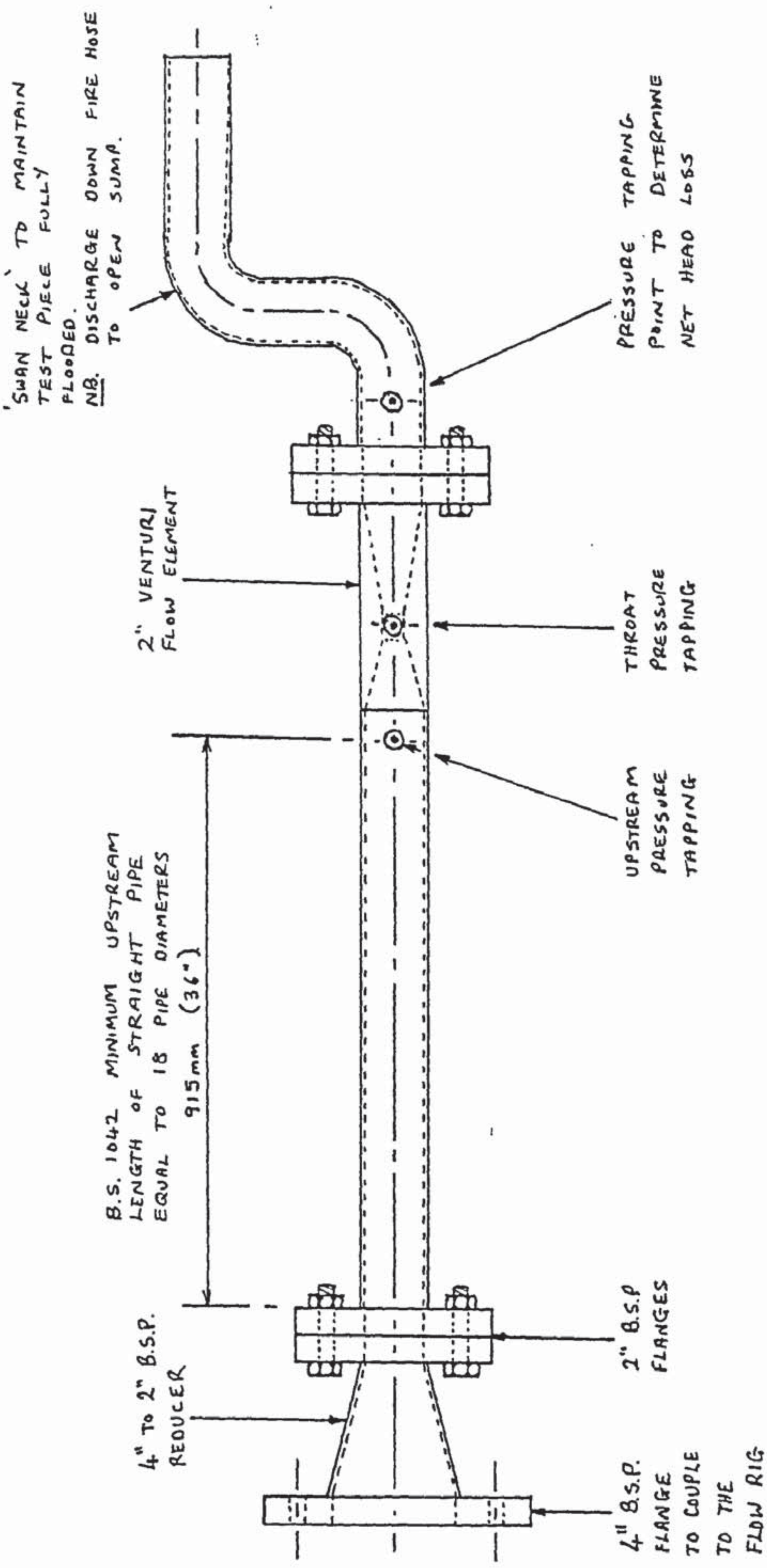


Fig.(3.1) : VENTURI TEST PIECE

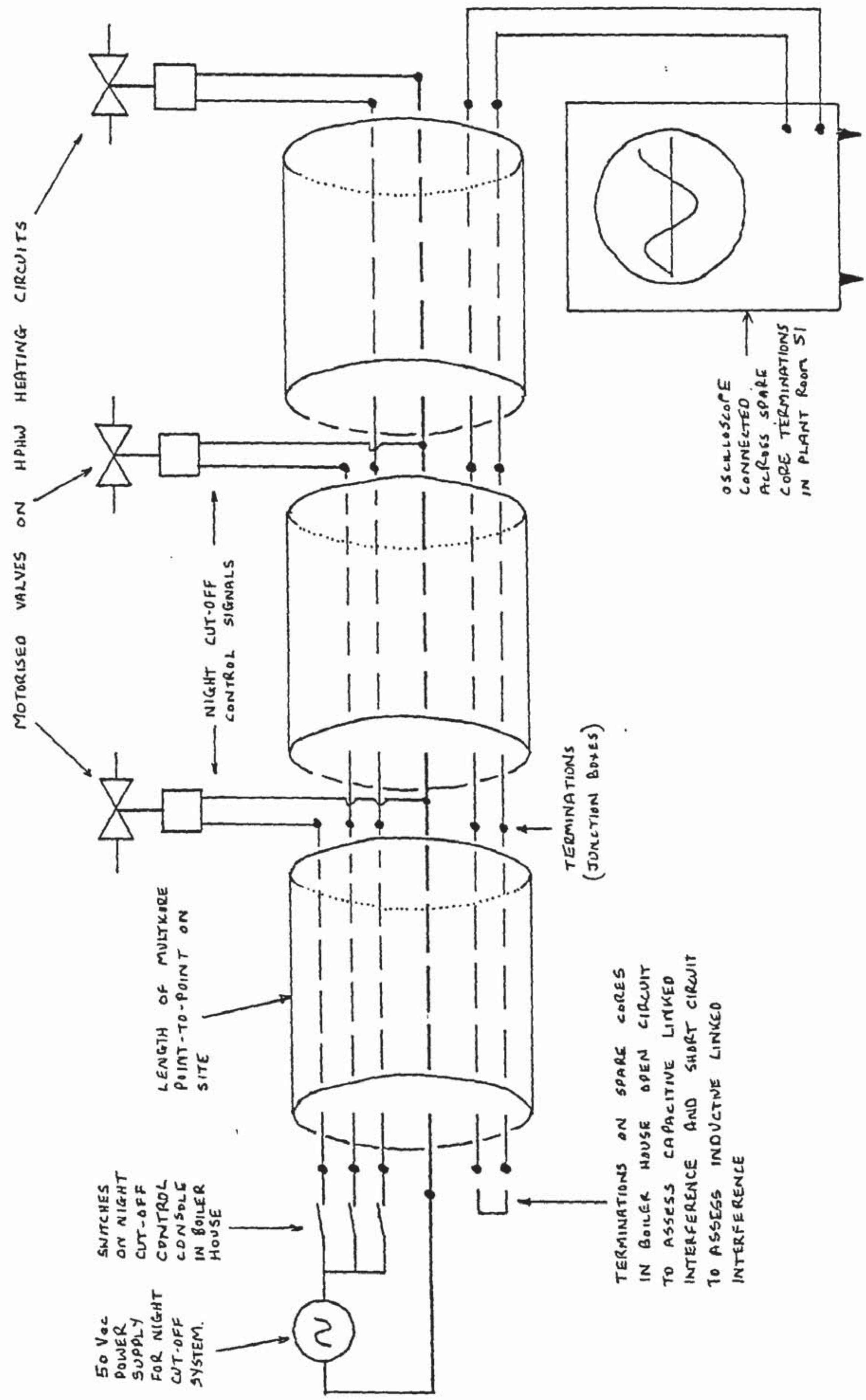


Fig.(3.2) : TESTS TO ASSESS INTERFERENCE ON SPARE NIGHT CUT-OFF SYSTEM CORES

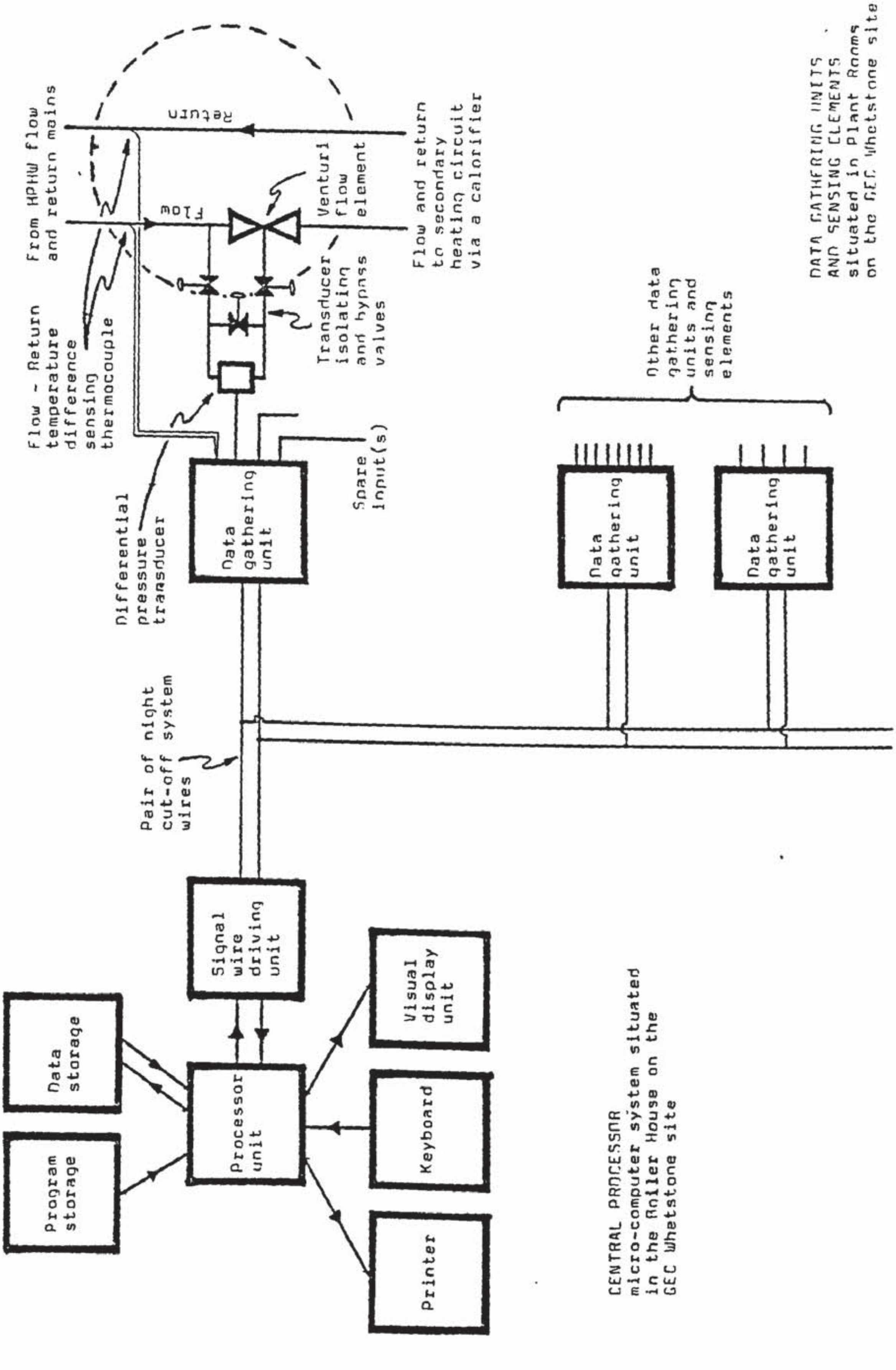


Fig.(3.3) : BASIC SYSTEM ARCHITECTURE

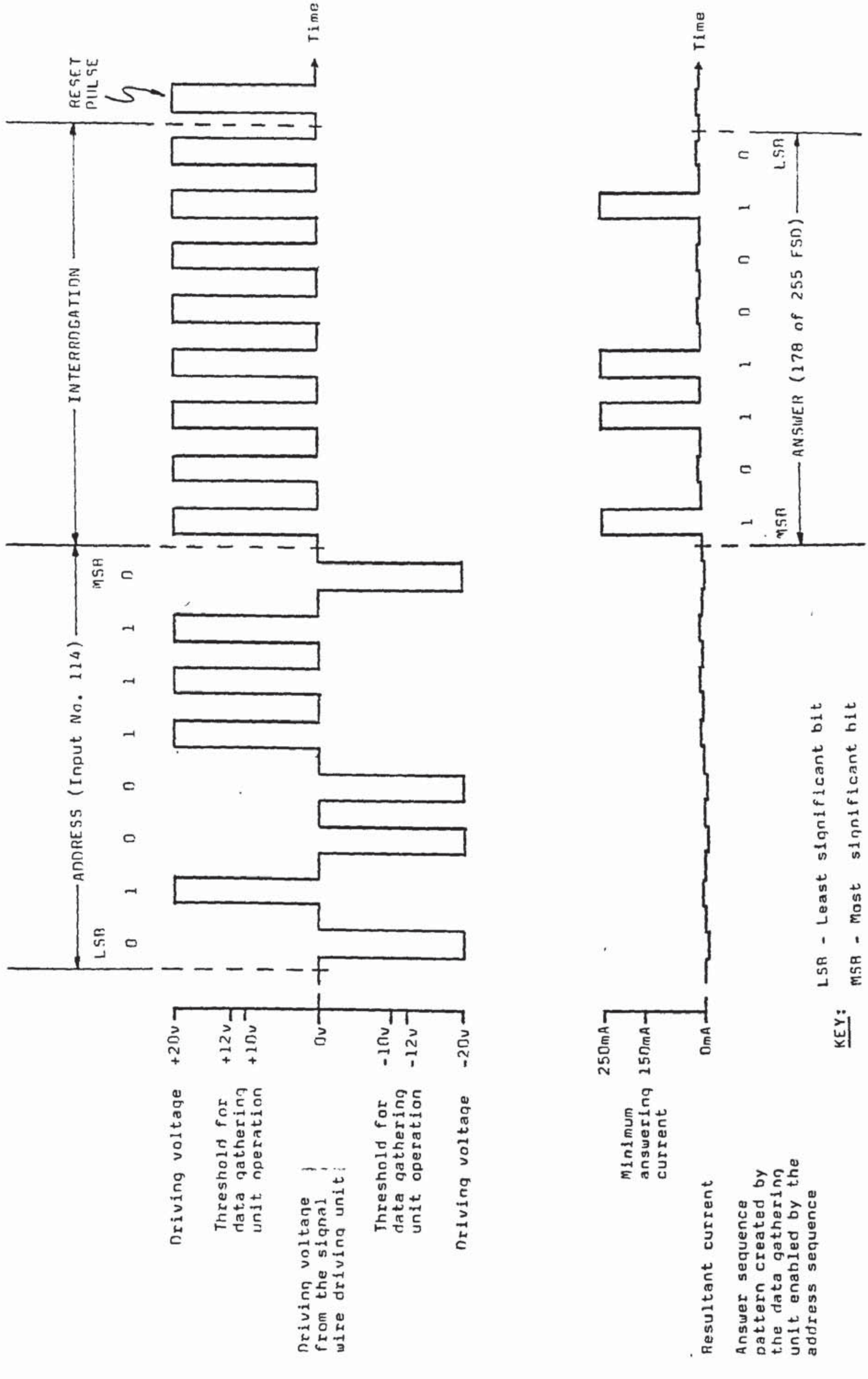


Fig.(3.4) : TIMING DIAGRAM OF DIGITAL SEQUENCES DURING A POLLING ROUTINE

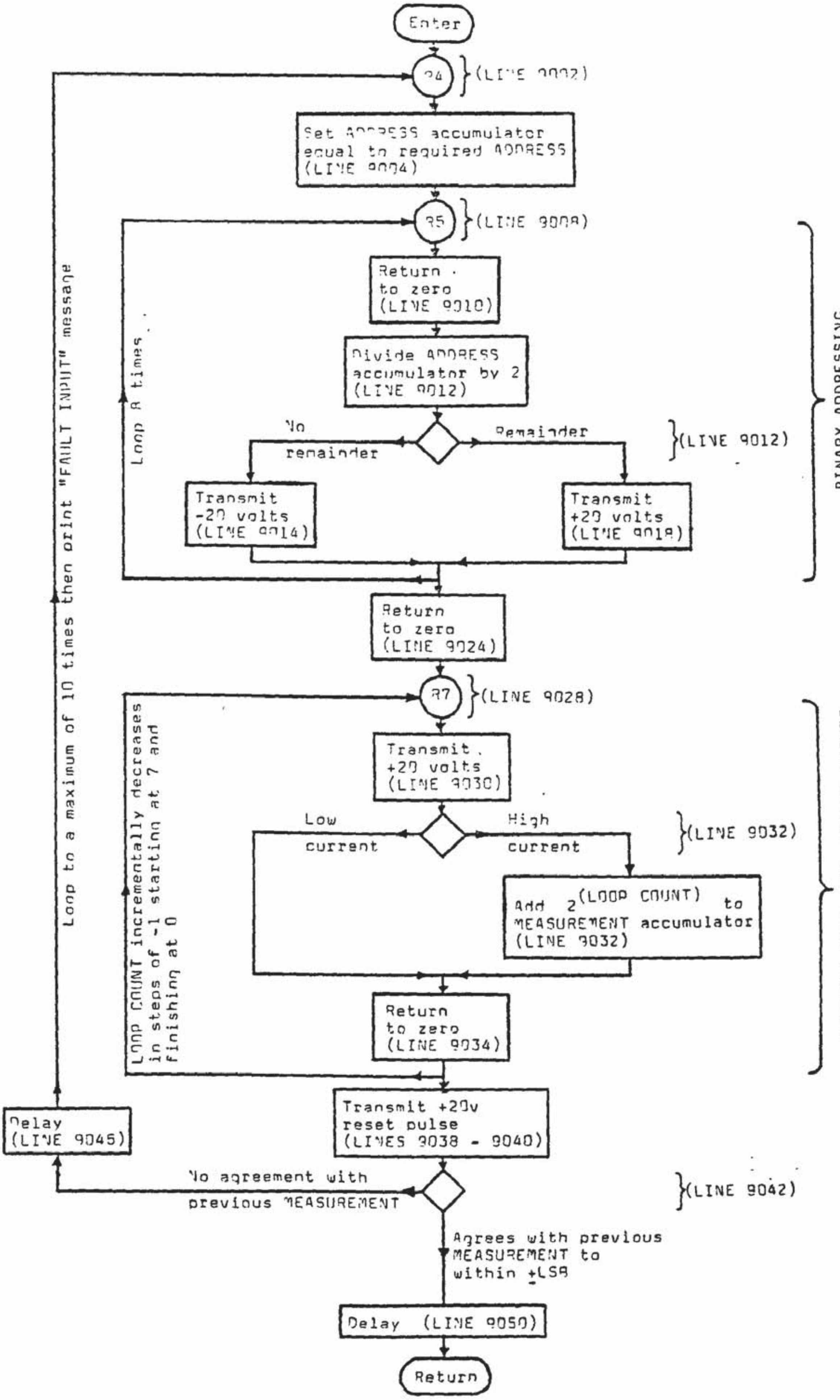


Fig.(3.5) : FLOW CHART REPRESENTATION OF THE POLLING SUBROUTINE

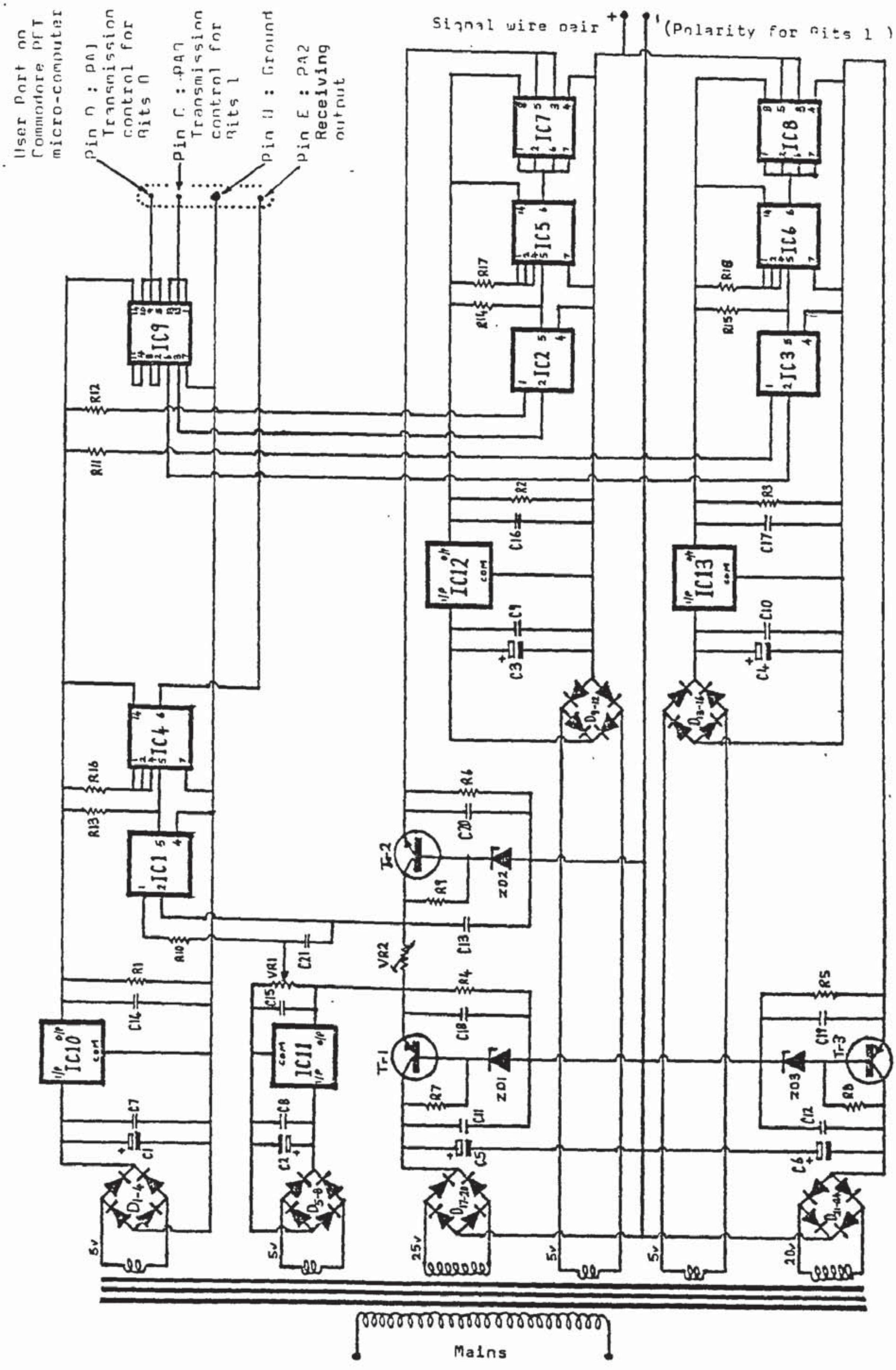


Fig.(3.6) : CIRCUIT DIAGRAM OF THE SIGNAL WIRE DRIVING UNIT

SEMI-CONDUCTORS

D1 - D4)	
D5 - D8)	
D9 - D12)	Silicon bridge rectifier, 200v, 1A
D13 - D16)	
D17 - D20)	
D21 - D24)	

IC1)		
IC2)		Single opto isolator
IC3)		
IC4)	7413	Dual 4-input NAND gate Schmitt Trigger
IC5)		
IC6)		
IC7)	DS3686N	Relay driver
IC8)		
IC9	7400	Quad 2-input NAND gates
IC10)		
IC11)	7805	+5v regulator
IC12)		
IC13)		
Tr1)	BFY51	Silicon npn transistor
Tr2)		
Tr3	BFX88	Silicon pnp transistor
ZD1	BZY93	11v and 15v zener diodes
ZD2)	BZY88	6.8v and 15v zener diodes
ZD3)		

RESISTORS

All resistors unless otherwise stated : 0.125 W rating
± 10% tolerance

R1	4K7	R7	220R	R13	12K
R2	4K7	R8	220R	R14	12K
R3	4K7	R9	220R	R15	12K
R4	4K7	R10	150R	R16	1K
R5	4K7	R11	150R	R17	1K
R6	4K7	R12	150R	R18	1K

VR1	1K	Carbon track preset potentiometer
VR2	40R	Wirewound rheostat preset at 25R

CAPACITORS

e - electrolytic *p* - polyester

C1	1000μ	25v	*e*	C11	220n	63v	*p*
C2	1000μ	25v	*e*	C12	220n	63v	*p*
C3	1000μ	25v	*e*	C13	220n	63v	*p*
C4	1000μ	25v	*e*	C14	470n	63v	*p*
C5	1000μ	63v	*e*	C15	470n	63v	*p*
C6	1000μ	63v	*e*	C16	470n	63v	*p*
C7	220n	63v	*p*	C17	470n	63v	*p*
C8	220n	63v	*p*	C18	470n	63v	*p*
C9	220n	63v	*p*	C19	470n	63v	*p*
C10	220n	63v	*p*	C20	470n	63v	*p*
				C21	470n	63v	*p*

MAINS TRANSFORMER

Mains primary : 240v, 50Hz
Secondaries : 6v, 0.5A / 6v, 0.5A / 6v, 0.5A / 6v, 0.5A /
20v, 0.5A / 25v, 0.5A

Fig.(3.7) : COMPONENT LIST FOR THE SIGNAL WIRE DRIVING UNIT

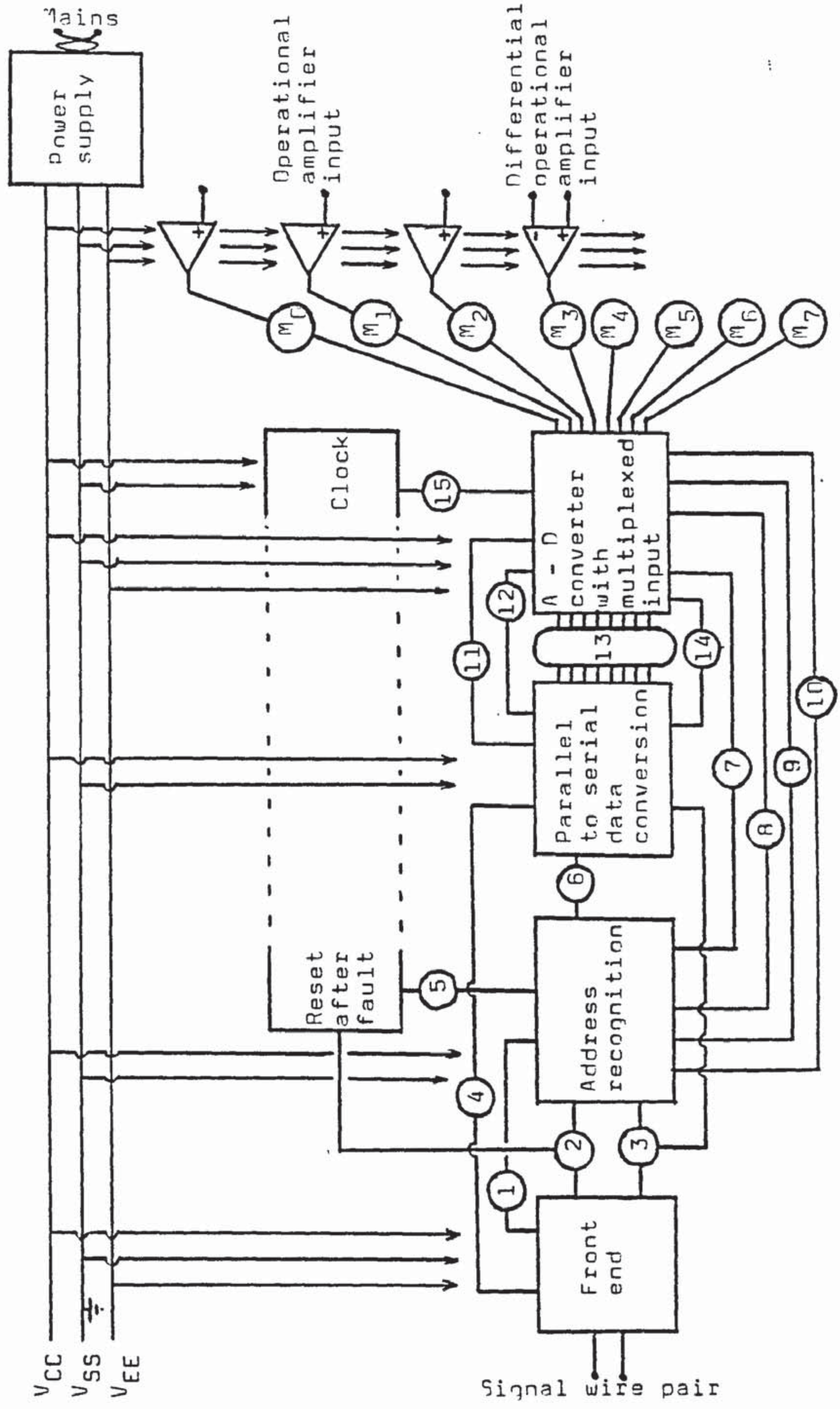


Fig.(3.8) : BLOCK DIAGRAM OF A DATA GATHERING UNIT

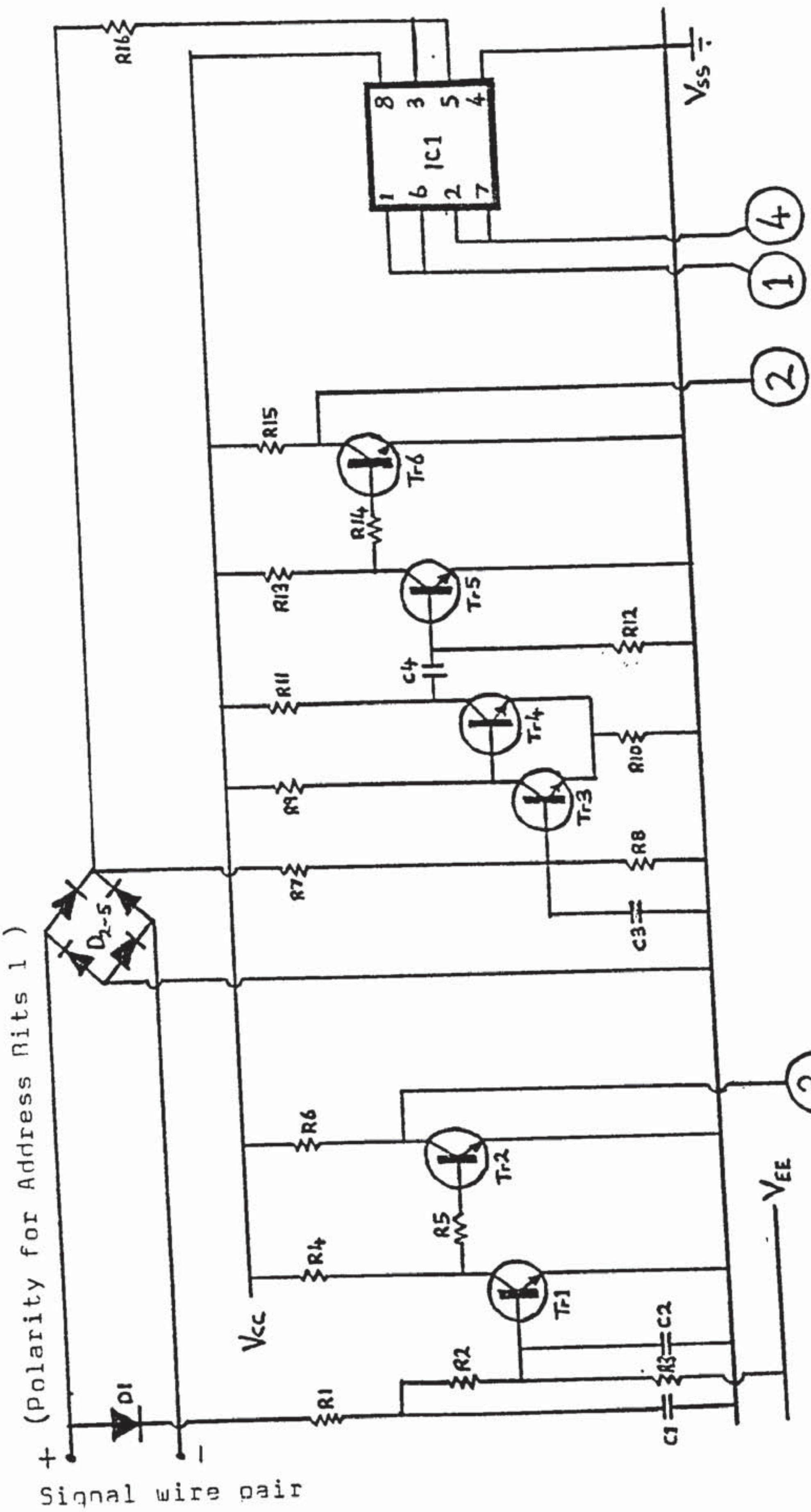


Fig.(3.9) : FRONT END CIRCUITRY

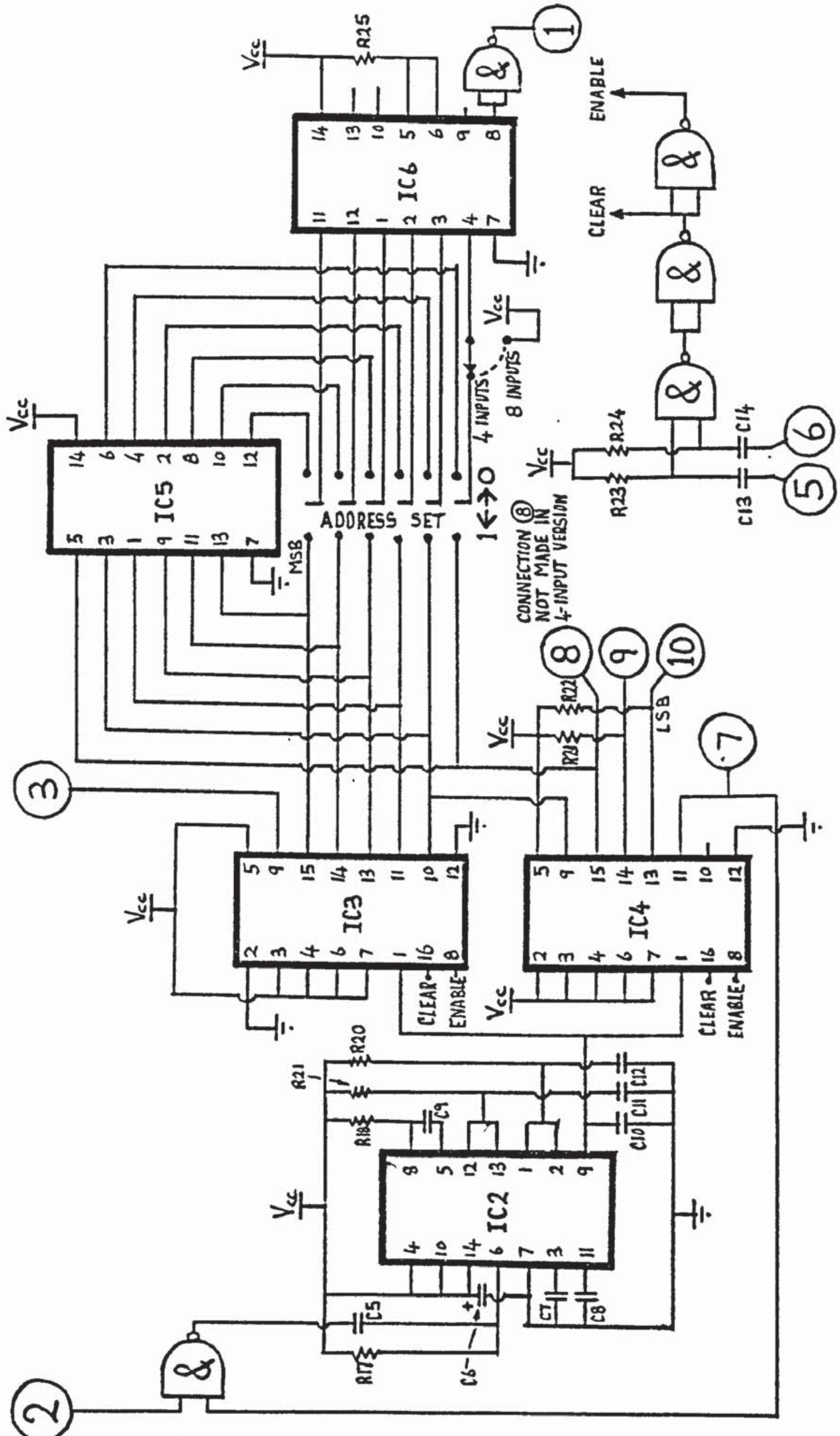


Fig.(3.10) : ADDRESS RECOGNITION CIRCUITRY

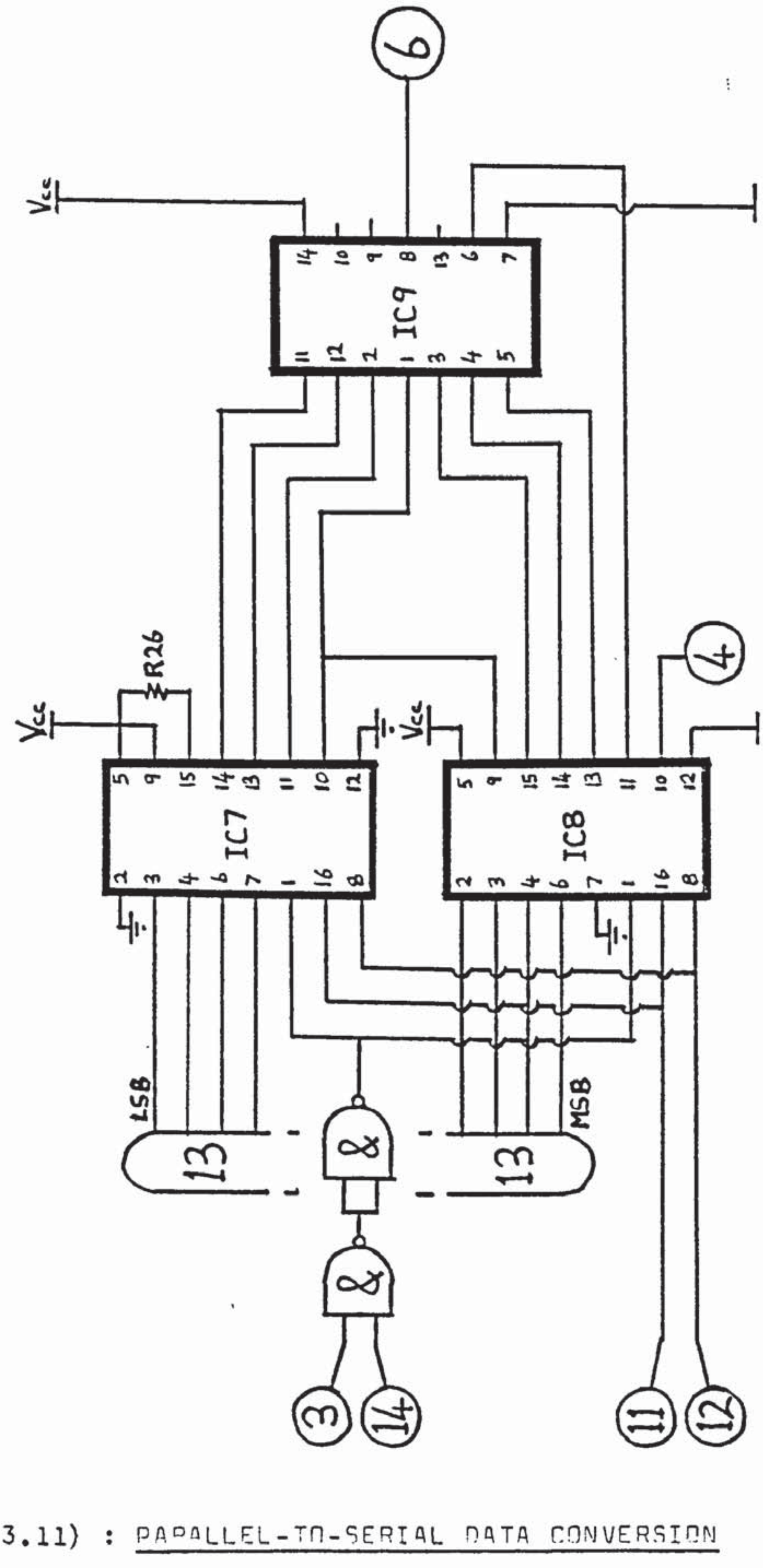


Fig.(3.11) : PARALLEL-TO-SERIAL DATA CONVERSION

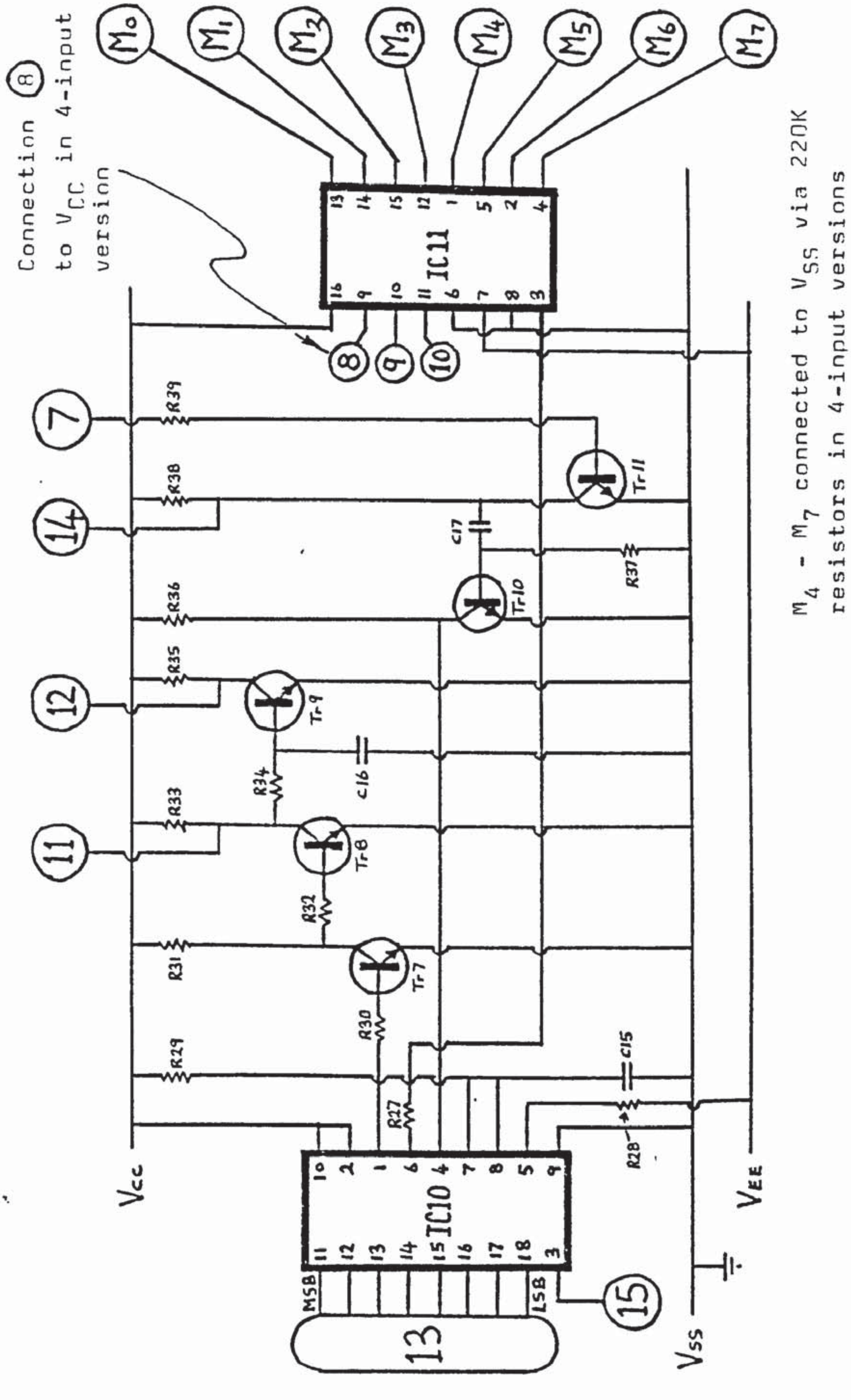


Fig.(3.12) : ANALOGUE-TO-DIGITAL CONVERTER WITH MULTIPLEXED INPUT

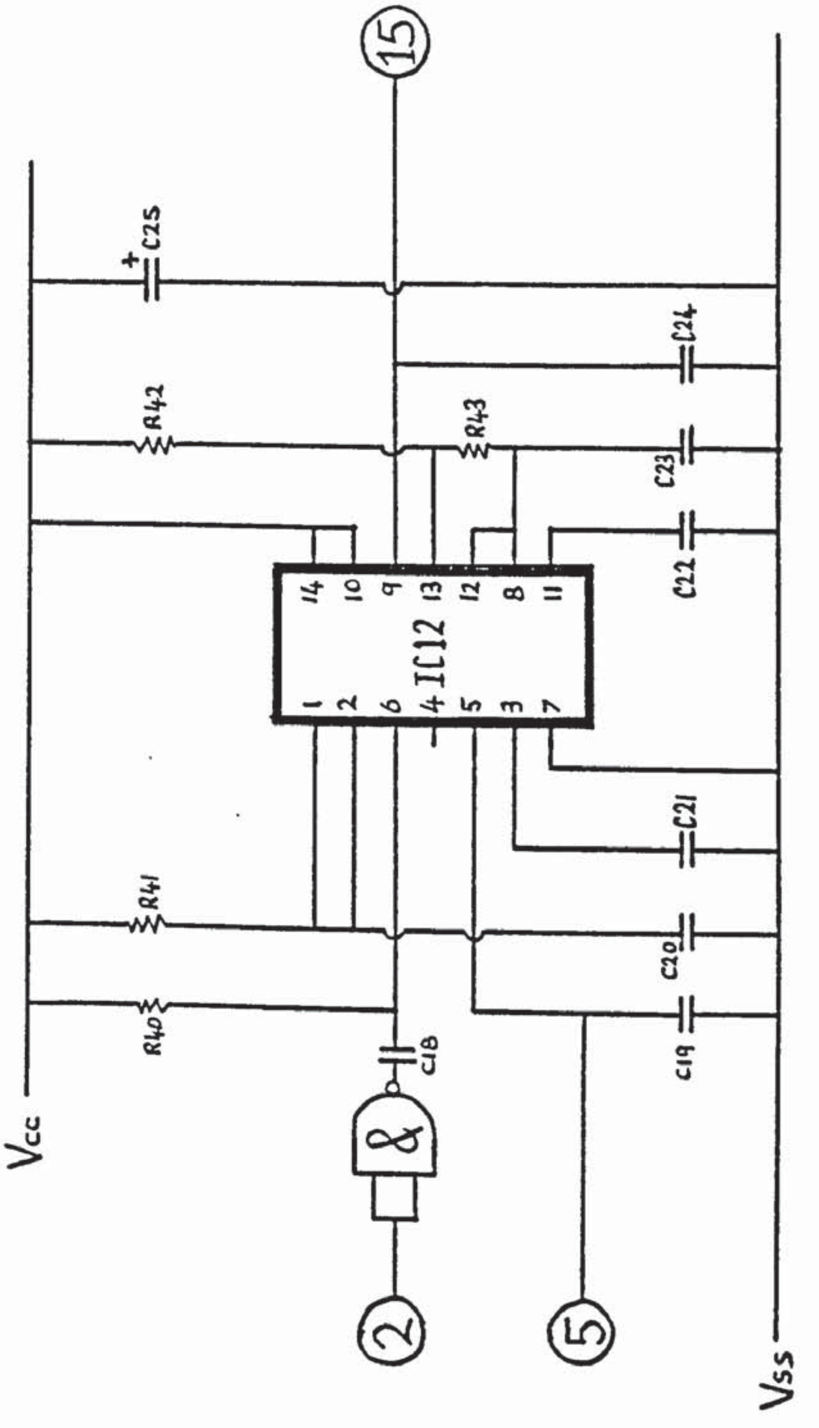


Fig.(3.13) : RESET-AFTER-FAULT AND CLOCK CIRCUITRY

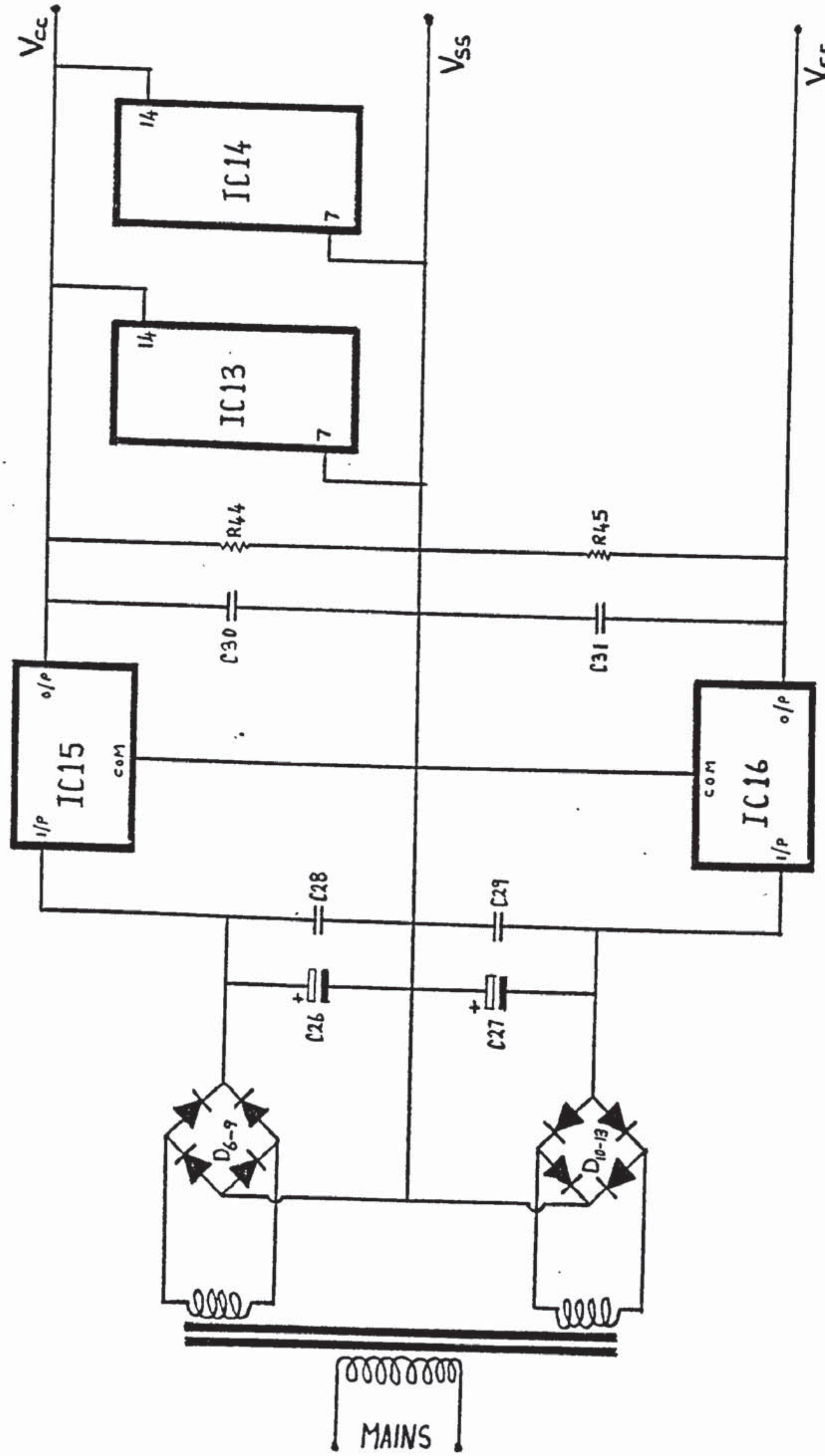


Fig.(3.14) : POWER SUPPLY

SEMI-CONDUCTORS

D1	1N4007	
D2 - D5)		
D6 - D9)	Silicon bridge rectifier, 200v, 1A	
D10 - D13)		
IC1	DS3686N	Relay driver
IC2	556	Dual timer
IC3	7496	5-bit shift register
IC4	7496	5-bit shift register
IC5	7404	Hex inverter
IC6	7430	8-input NAND gate
IC7	7496	5-bit shift register
IC8	7496	5-bit shift register
IC9	7430	8-input NAND gate
IC10	ZN427E	Analogue-to-digital converter
IC11	4051B	8-input analogue multiplexer
IC12	556	Dual timer
IC13	7400	Quad 2-input NAND gates
IC14	7400	Quad 2-input NAND gates
IC15	7805	+5v regulator with heat sink
IC16	7905	-5v regulator.
Tr1 - Tr11	BC108	Silicon npn transistors

RESISTORS

All resistors unless otherwise stated : 0.125 W rating
± 10% tolerance

R1	39K		R17	10K	R31	4K7
R2	2K2		R18	10K	R32	10K
R3	22K		R19	100K	R33	1K
R4	2K2		R20	100K	R34	47K
R5	2K2		R21	4K7	R35	1K
R6	2K2		R22	4K7	R36	2K2
R7	33K		R23	10K	R37	10K
R8	3K9		R24	10K	R38	2K2
R9	4K7		R25	1K	R39	10K
R10	470R		R26	2K2	R40	10K
R11	4K7		R27	3K9	R41	1M
R12	4K7		R28	82K	R42	10K
R13	4K7		R29	390R	R43	12K
R14	10K		R30	47K	R44	4K7
R15	2K2				R45	4K7
R16	68R	4 W wirewound				

Four 220K for 4-input version

CAPACITORS

c - ceramic e - electrolytic p - polyester t - tantalum
ll - low loss (silvered mica, polycarbonate, polystyrene or polypropylene)

C1	1n	100v	c	C17	100n	100v	c
C2	1n	100v	c	C18	1n	100v	c
C3	1n	100v	c	C19	1n	100v	c
C4	1n	100v	c	C20	1μ	10v	ll
C5	1n	100v	c	C21	10n	100v	c
C6	47μ	6v3	t	C22	10n	100v	c
C7	10n	100v	c	C23	4n7	10v	ll
C8	10n	100v	c	C24	1n	100v	c
C9	1n	100v	c	C25	47μ	6v3	t
C10	1n	100v	c	C26	2200μ	25v	e
C11	10n	10v	ll	C27	1000μ	25v	e
C12	10n	10v	ll	C28	220n	250v	p
C13	100n	100v	c	C29	220n	250v	p
C14	100n	100v	c	C30	470n	250v	p
C15	1μ	10v	ll	C31	470n	250v	p
C16	100n	10v	c				

POWER SUPPLY TRANSFORMER Mains primary : 240v, 50Hz
Secondaries : 6v, 1A / 6v, 1A

Fig.(3.15) : COMPONENT LIST FOR ONE DATA GATHERING UNIT

(Excludes components for operational)
(amplifier inputs)

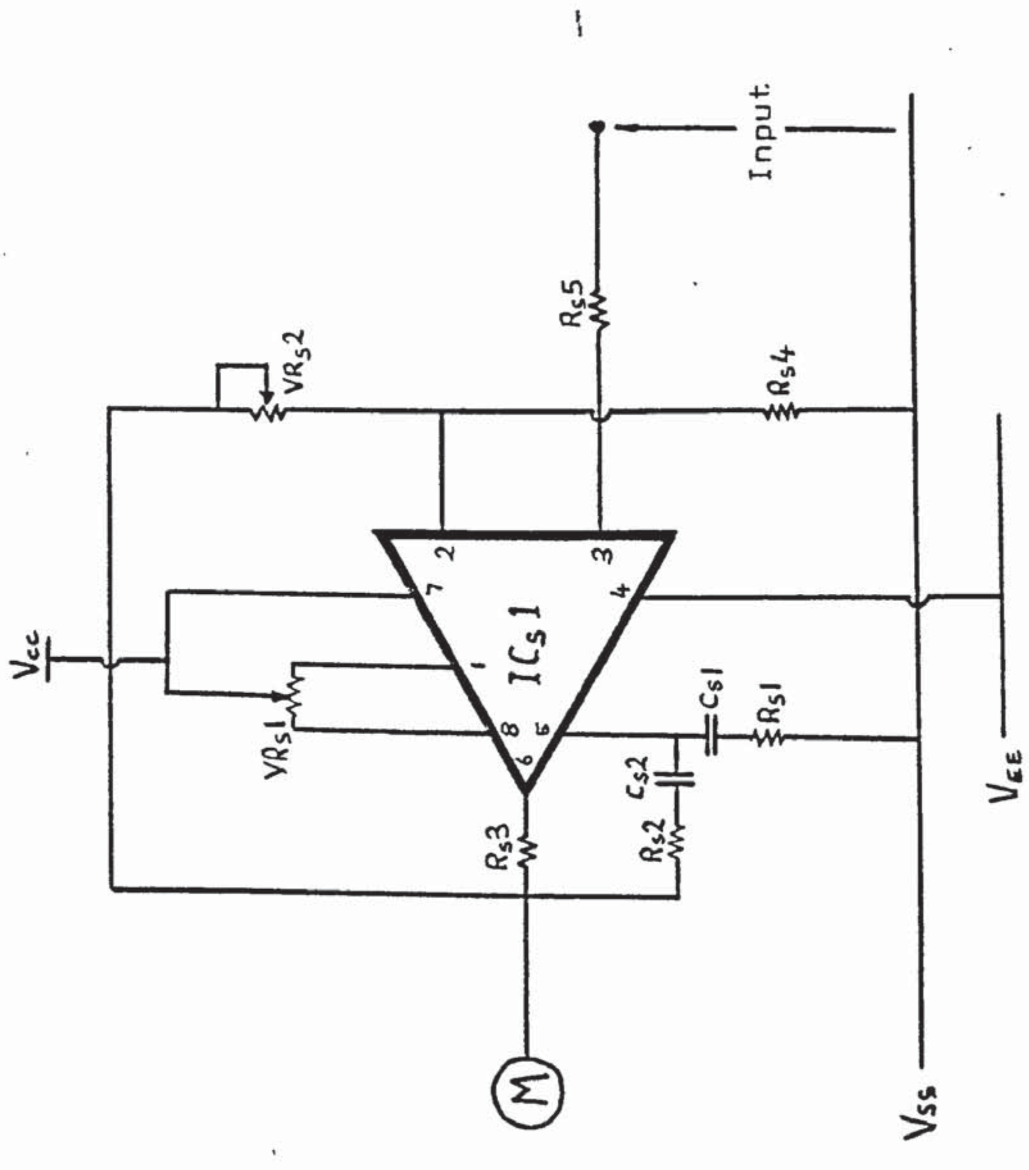


Fig.(3.16) : STANDARD OPERATIONAL AMPLIFIER INPUT

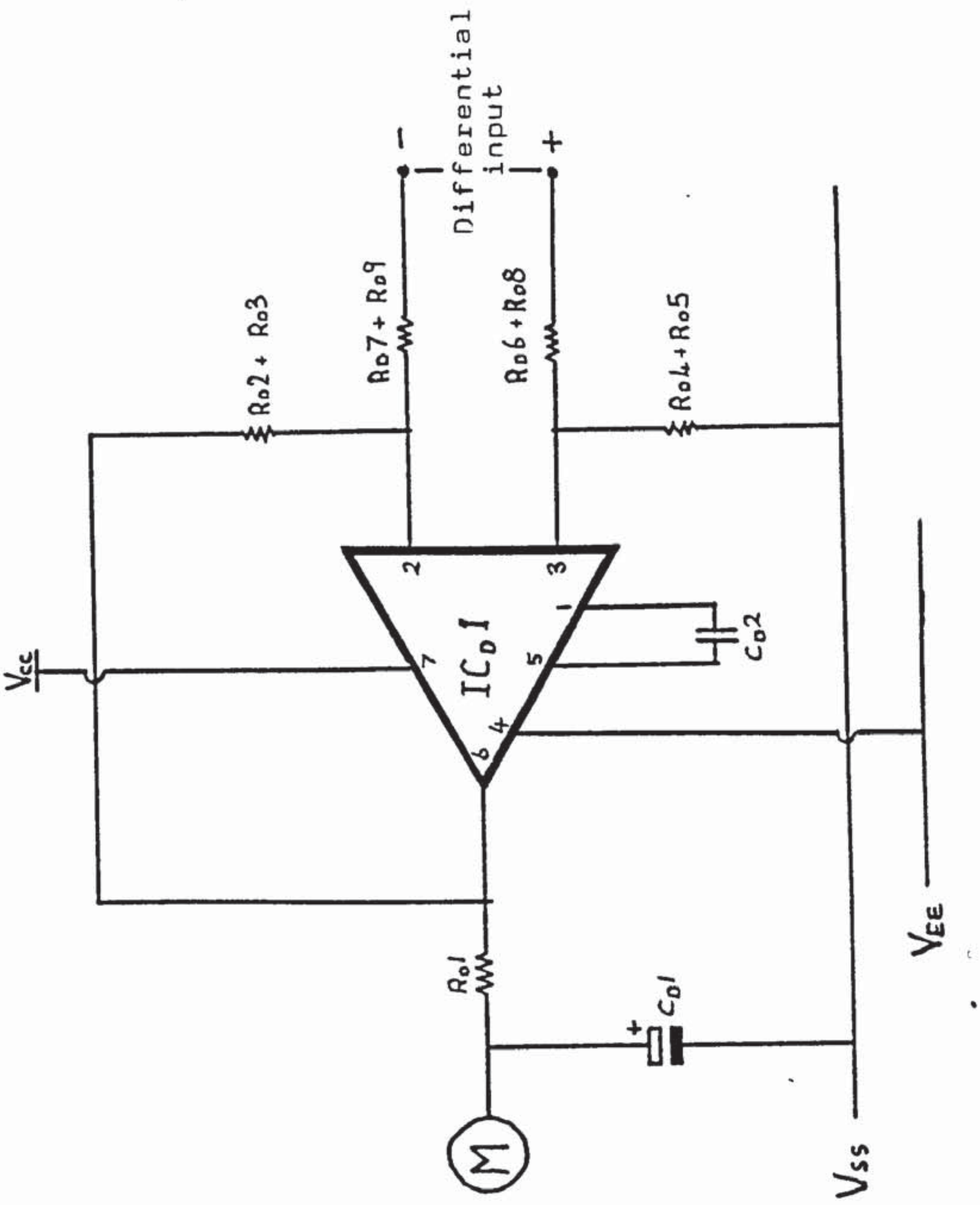


Fig.(3.17) : DIFFERENTIAL OPERATIONAL AMPLIFIER INPUT

COMPONENT LIST FOR ONE STANDARD OPERATIONAL AMPLIFIER INPUT

SEMI-CONDUCTORS

IC_S1	725CN	Instrumentation amplifier

RESISTORS

All resistors unless otherwise stated : 0.125 W rating
± 10% tolerance

R_S1	10R	R_S4	100R	±2% tolerance
R_S2	39R	R_S5	100R	
R_S3	51R			

VR_S1	100K	Carbon track preset potentiometer
VR_S2	100K	Carbon track preset potentiometer

CAPACITORS

C_S1	47n	100v	ceramic
C_S2	22n	100v	ceramic

COMPONENT LIST FOR ONE DIFFERENTIAL OPERATIONAL AMPLIFIER INPUT

SEMI-CONDUCTORS

IC_D1	LM308A	Operational amplifier

RESISTORS

All resistors unless otherwise stated : 0.125 W rating
Low tolerance, high stability

R_D1	12K	±10% tolerance	R_D6	13K
R_D2	1M		R_D7	13K
R_D3	2M7		R_D8	3K9
R_D4	1M		R_D9	3K9
R_D5	2M7			

CAPACITORS

C_D1	220μ	10v	electrolytic
C_D2	68p	350v	silvered mica

Fig.(3.18) : COMPONENT LISTS FOR OPERATIONAL AMPLIFIER INPUTS

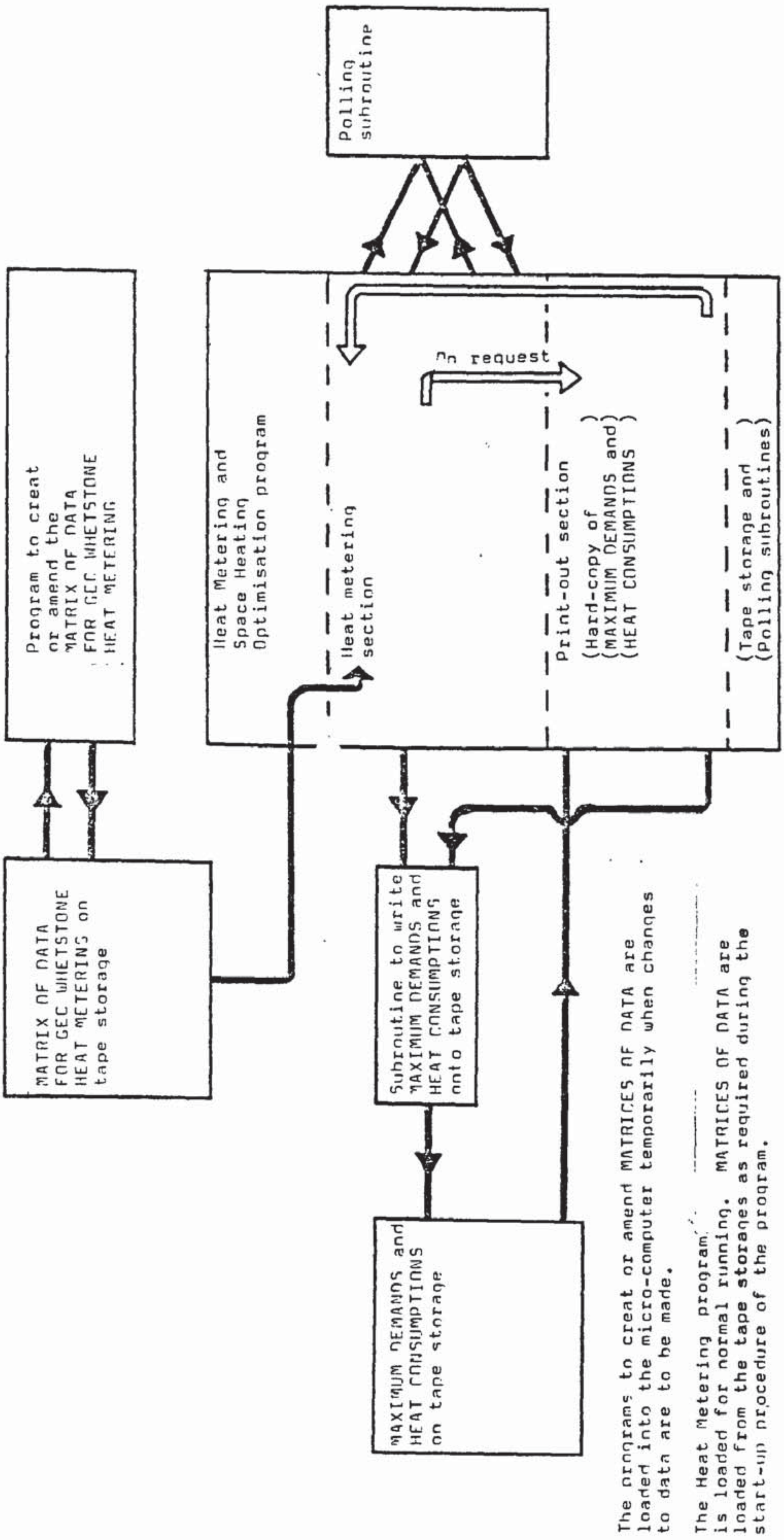


Fig.(3.19) : SOFTWARE ORGANISATION

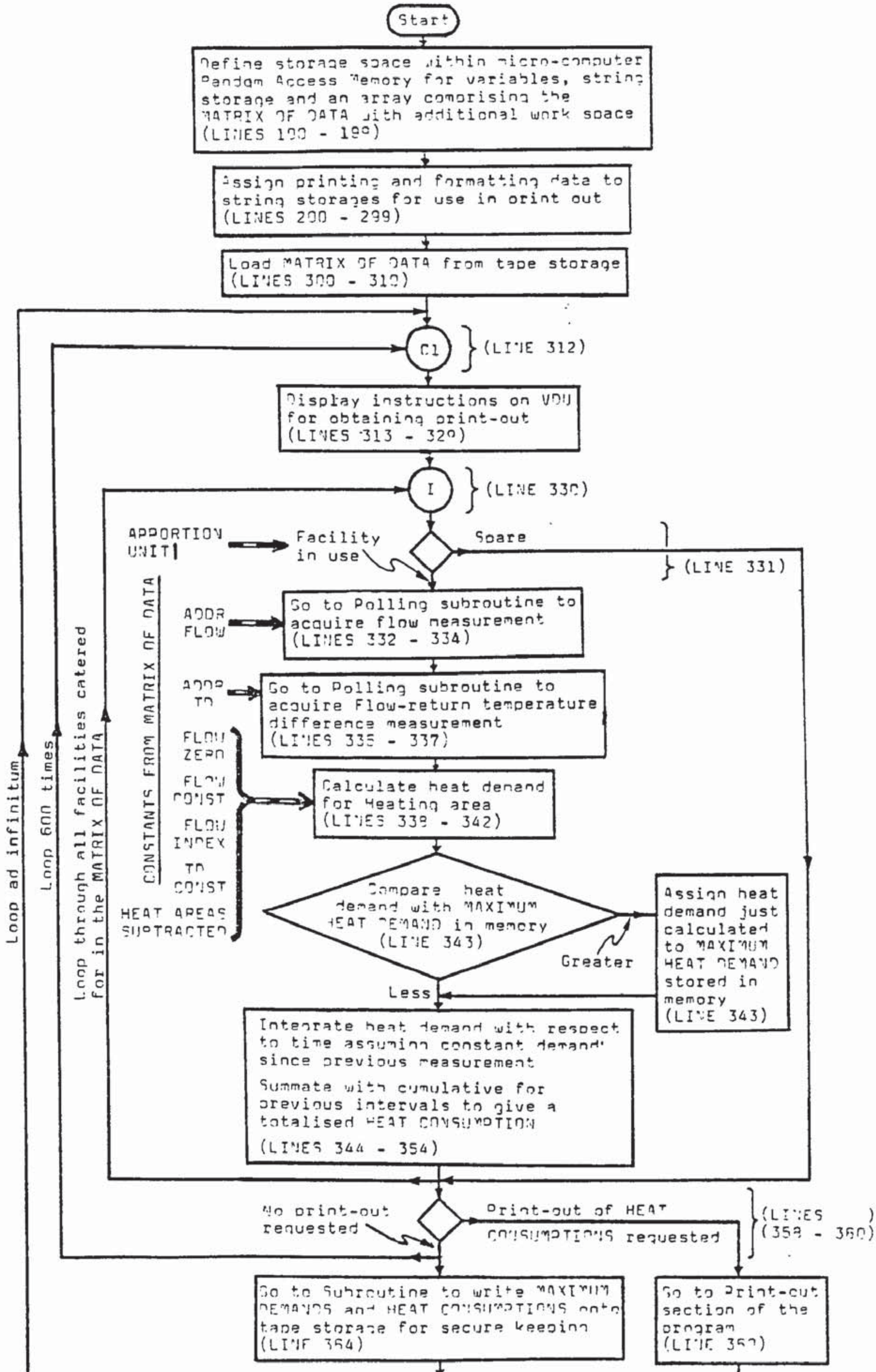


Fig.(3.20) : FLOW CHART REPRESENTATION OF THE HEAT METERING PROGRAM

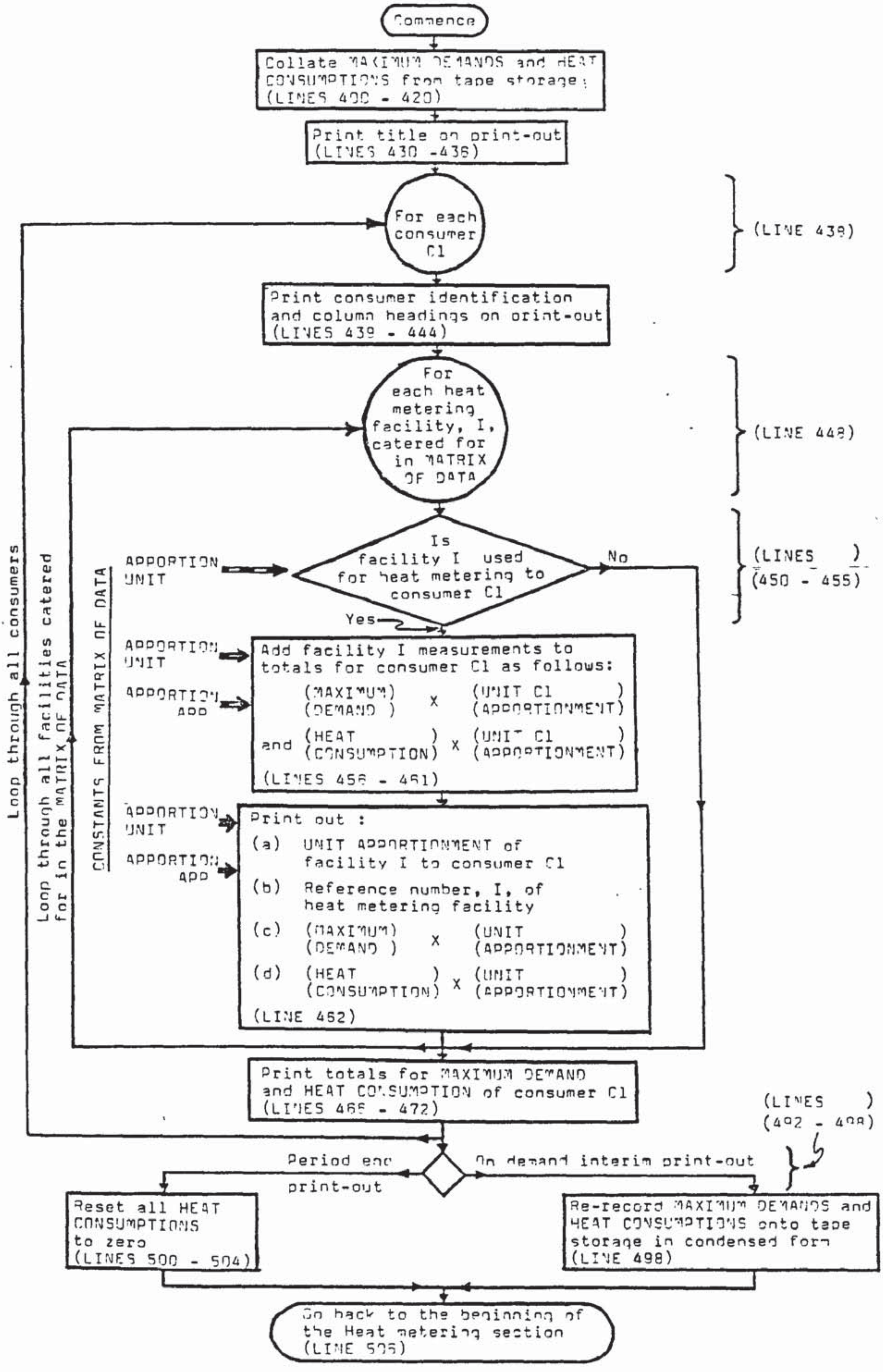


Fig.(3.21) : FLOW CHART REPRESENTATION OF HEAT METERING PRINT-OUT PROGRAM

```
READY.

103 I1=0 C3=0
104 D1=TI D2=0
106 F1=0
109 I=0
110 J=0
111 K=0
113 M1=60 M2=7
116 P1=0 P2=0 P3=0 P4=0 P5=0
119 R1=0 R2=0 R3=0 R4=0 R5=0 R6=0 R7=0
119 S1=0 S2=0
120 T1=0
138 DIM H(M1,20)
181 DIM U$(M2)
201 U$(1)="GTL"
202 U$(2)="ESL"
203 U$(3)="MEL"
204 U$(4)="CML"
205 U$(5)="MCS"
206 U$(6)="NNC"
207 U$(7)="EST"
220 A$=" "
290 V$="APP            HEATING AREA      MAX HEAT DEMAND
                                                          HEAT CONSUMED"
292 W$="                                     BTU/HR          THERMS"
294 X$="Z.99                ZZ               999999999
                                                          9999999999.99"
296 Y$="AAAAAAAA                             999999999
                                                          9999999999.99"
298 Z$="TOTALS  "
300 PRINT"REPLACE PROGRAM TAPE IN CASSETTE UNIT 1 WITH DATA MATRIX
                                                                  TAPE"
302 OPEN1,1,0,"MATRIX"
304 FOR I=0TOM1
305 FOR J=0TO16
306 INPUT#1,H(I,J)
307 NEXT
308 H(I,19)=D1
309 NEXT I
310 CLOSE 1
311 OPEN1,2,1,"OUTPUT"
312 FOR C1=0TO600
313 PRINT
314 PRINT TI$
315 PRINT
316 PRINT"SYSTEM HEAT METERING"
317 PRINT
318 PRINT"TO OBTAIN PRINT-OUT :"
319 PRINT
320 PRINT"(A) SWITCH-ON PRINTER"
321 PRINT"(B) PRESS 'P'-ONCE
322 PRINT"(C) FOLLOW THE SUBSEQUENT INSTRUCTIONS      DISPLAYED ON THIS
                                                                   VDU"
324 PRINT
325 PRINT"(INITIAL RESPONSE CAN TAKE UPTO 15 MINS)"
326 PRINT
327 PRINT"HEAT   F-R TD   HEAT DEMAND"
328 PRINT"AREA   DEG.F      BTU/HR"
329 PRINT
330 FOR I=1TOM1
331 IF H(I,3)=0AND H(I,11)=0AND H(I,13)=0AND H(I,15)=0 THEN GOTO356
332 P1=H(I,0)
333 GOSUB9000
334 F1=R2
335 P1=H(I,1)
336 GOSUB9000
```

continued

Fig.(3.22) : LISTING OF THE HEAT METERING PROGRAM continuation

```
337 T1=P2
338 F1=H(H(I,6),16)+H(H(I,7),16)+H(H(I,8),16)
339 IF F1<=H(I,2) GOTO342
340 H(I,17)=H(I,5)*T1+H(I,3)*SQR((F1-H(I,2))/H(I,4))-F1
341 GOTO343
342 H(I,17)=0
343 IF H(I,17)>H(I,18) THEN H(I,18)=H(I,17)
344 D1=TI
345 IF D1>H(I,19) GOTO350
346 D2=5184000-H(I,19)+D1
348 GOTO352
350 D2=D1-H(I,19)
352 H(I,19)=D1
354 H(I,20)=H(I,20)+H(I,17)*D2/21600000000
355 PRINT I,T1,INT(H(I,17)),F1
356 NEXT I
358 GET A$
360 IF A$="P"GOTO400
362 NEXT C1
364 GOSUB600
366 GOTO312
400 CLOSE1
402 PRINT"REWIND TAPE ON CASSETTE UNIT 2"
404 PRINT"THEN TYPE  CONT  & PRESS RETURN"
406 END
408 OPEN1,2,0,"OUTPUT"
410 IF ST=64 GOTO420
412 INPUT#1,I,P2,P3
414 IF P2>H(I,18) THEN H(I,18)=P2
416 H(I,20)=H(I,20)+P3
418 GOTO410
420 CLOSE1
422 OPEN2,4,2
424 OPEN3,4,0
426 OPEN4,4,1
428 OPEN5,4,4
430 PRINT#2
432 PRINT#5
434 PRINT#3,"HEAT CONSUMPTION GEC WHETSTONE : PERIOD"
436 PRINT#3
438 FOR C1=1TOM2
439 PRINT#3
440 PRINT#3,U$(C1)
441 PRINT#3
442 PRINT#3,V$
443 PRINT#3,W$
444 PRINT#3
445 P4=0 P5=0
446 PRINT#2,X$
448 FOR I=1TOM1
450 FOR K=9TO15STEP2
452 IF H(I,K)=C1 GOTO456
454 NEXT
455 GOTO464
456 P2=H(I,K+1)*H(I,18)
458 P3=H(I,K+1)*H(I,20)
460 LET P4=P4+P2
461 LET P5=P5+P3
462 PRINT#4,H(I,K+1),I,P2,P3
464 NEXT I
466 PRINT#3
468 PRINT#2,Y$
470 PRINT#4,Z$,CHR$(29),P4,P5
472 PRINT#3
474 NEXT C1
475 CLOSE2
```

continued

Fig.(3.22) continued : <u>LISTING OF THE HEAT METERING PROGRAM</u>

continuation

```
478 CLOSE3
480 CLOSE4
482 CLOSE5
484 PRINT"REWIND TAPE ON CASSETTE UNIT 2"
486 PRINT"THEN TYPE  CONT  & PRESS RETURN"
488 END
490 OPEN1,2,1,"OUTPUT"
492 C3=1
494 PRINT"IF PERIOD-END PRINT-OUT TYPE 0 OR ELSE  TYPE 1"
496 INPUT C3
498 IF C3<>0 THEN GOSUB600
500 FOR I=0TOM1
502 H(I,18)=0
504 NEXT
506 GOTO312
600 FOR I=1TOM1
602 IF H(I,9)=0AND H(I,11)=0AND H(I,13)=0AND H(I,15)=0 THEN GOTO608
604 PRINT#1,I",",H(I,18)",",H(I,20)
606 H(I,18)=0:H(I,20)=0
608 NEXT I
610 RETURN
9000 R2=-2
9002 FOR R4=0TO9
9004 R3=R1
9006 POKE 59459,251
9008 FOR R5=0TO7
9010 POKE 59471,0
9012 IF(R3/2)>INT(R3/2)GOTO9018
9014 POKE 59471,2
9016 GOTO9020
9018 POKE 59471,1
9020 R3=INT(R3/2)
9022 NEXT
9024 POKE 59471,0
9026 R6=0
9028 FOR R7=7TO0STEP-1
9030 POKE 59471,1
9032 IF PEEK(59471)=5 THEN R6=R6+2↑R7
9034 POKE 59471,0
9036 NEXT
9038 POKE 59471,1
9040 POKE 59471,0
9042 IF R6>(R2-1)AND R6<(R2+1)GOTO9050
9044 R2=R6
9046 GOSUB9100
9048 NEXT R4
9049 PRINT"FAULT INPUT",R1
9050 GOSUB9100
9052 RETURN
9100 S1=0
9102 FOR S2=0TO500
9104 S1=S1+S2
9106 NEXT S2
9108 RETURN
READY.
```

Fig.(3.22) continued : LISTING OF THE HEAT METERING PROGRAM

HEAT CONSUMPTION REC WHETSTONE PERIOD 1 1982/83

STL

APP	HEATING AREA	MAX HEAT DEMAND BTU/HR	HEAT CONSUMED THERMS
0.15	01		.00
1.00	02	1210412	173.21
0.05	03	4213	.04
0.47	05	1250655	[illegible]
0.38	06		.00
0.37	11		.00
1.00	12		.00
0.61	13		.00
0.00	16		.00
0.04	17	108793	3.25
TOTALS		2564219	1055.32

ESL

APP	HEATING AREA	MAX HEAT DEMAND BTU/HR	HEAT CONSUMED THERMS
0.53	05	1421815	985.35
1.00	07	3747419	1302.48
0.27	08		.00
1.00	09	412520	17.66
0.36	10		.00
0.36	13		.00
1.00	14	89947	158.68
1.00	15		.00
TOTALS		5671702	2464.19

MEL

APP	HEATING AREA	MAX HEAT DEMAND BTU/HR	HEAT CONSUMED THERMS
0.28	01		.00
0.39	03	32902	.37
0.23	04	315993	68.54
TOTALS		348896	68.91

CML

APP	HEATING AREA	MAX HEAT DEMAND BTU/HR	HEAT CONSUMED THERMS
TOTALS			.00

MCS

APP	HEATING AREA	MAX HEAT DEMAND BTU/HR	HEAT CONSUMED THERMS
0.55	04	755637	163.91
TOTALS		755637	163.91

NNC

APP	HEATING AREA	MAX HEAT DEMAND BTU/HR	HEAT CONSUMED THERMS
0.56	03	47244	.53
0.20	04	274777	59.60
0.73	08		.00
0.03	13		.00
0.93	17	2528047	192.02
1.00	20	2278197	1063.07
TOTALS		5128267	1315.24

EST

APP	HEATING AREA	MAX HEAT DEMAND BTU/HR	HEAT CONSUMED THERMS
0.57	01		.00
0.02	04	27477	5.96
0.02	06		.00
0.04	10		.00
0.03	11		.00
0.03	17	81549	6.19
TOTALS		109027	12.15

Fig.(3.23) : HEAT METERING PRINT-OUT

MATRIX OF DATA FOR GEC WHETSTONE HEAT METERING

HEAT AREA	ADDR FLOW	ADDR TD	FLOW ZERO	FLOW CONST	FLOW INDEX	TD CONST	HEAT AREAS SUBTRACTED			APPORTION UNIT	APP
00					1.00	.00	00	00	00	00	0.00
										00	0.00
										00	0.00
										00	0.00
01	63	62		2784	190.00	1.00	00	00	00	01	0.15
										03	0.26
										07	0.57
										00	0.00
02	23	20	11	19686	172.00	1.00	01	00	00	01	1.00
										00	0.00
										00	0.00
										00	0.00
03	27	26		8661	172.00	1.00	00	00	00	01	0.05
										03	0.39
										06	0.56
										00	0.00
04	31	30		8661	172.00	1.00	00	00	00	03	0.23
										05	0.55
										06	0.20
										07	0.02
05	35	34		19686	172.00	1.00	00	00	00	01	0.47
										02	0.53
										00	0.00
										00	0.00
06	43	42		89080	190.00	1.00	00	00	00	01	0.98
										07	0.02
										00	0.00
										00	0.00
07	51	50		40650	190.00	1.00	00	00	00	02	1.00
										00	0.00
										00	0.00
										00	0.00
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
57					1.00	.00	00	00	00	00	0.00
										00	0.00
										00	0.00
										00	0.00
58					1.00	.00	00	00	00	00	0.00
										00	0.00
										00	0.00
										00	0.00
59					1.00	.00	00	00	00	00	0.00
										00	0.00
										00	0.00
										00	0.00
60					1.00	.00	00	00	00	00	0.00
										00	0.00
										00	0.00
										00	0.00

Fig.(3.24) : MATRIX OF DATA FOR GEC WHETSTONE HEAT METERING

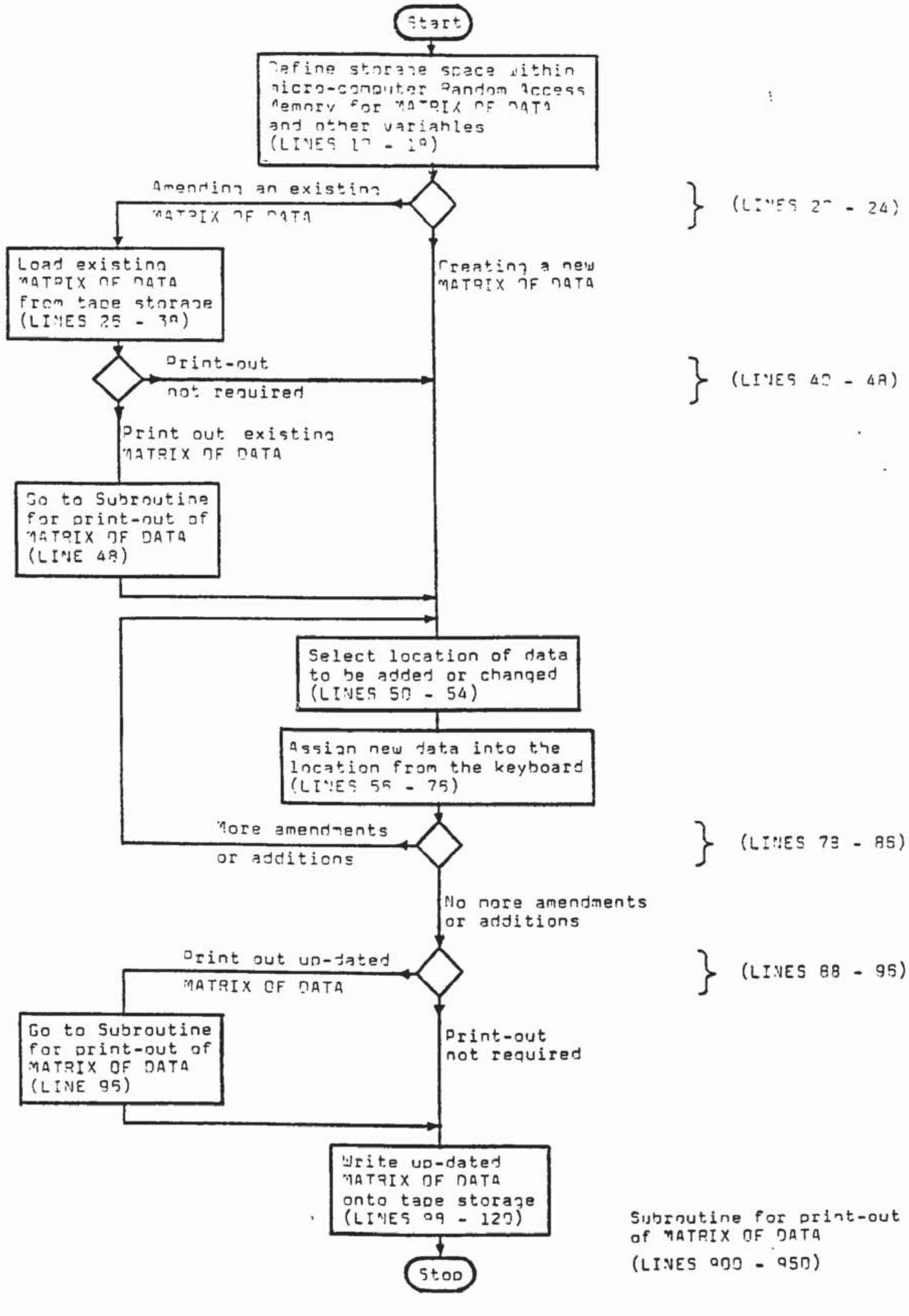


Fig.(3.25) : FLOW CHART REPRESENTATION OF THE PROGRAM USED FOR AMENDING THE MATRIX OF HEAT METERING DATA

```
READY.

10 M=60
12 DIM H(M,16)
13 FOR J=0TO16
14 H(0,J)=0
15 NEXT
16 FOR I=0TOM
17 H(I,4)=1
18 NEXT
20 PRINT"IF AMENDING EXISTING DATA MATRIX TYPE    GOTO 26"
22 PRINT"IF CREATING A NEW DATA MATRIX TYPE      GOTO 50"
24 END
26 OPEN 1,2,0,"MATRIX"
28 FOR I=0TOM
30 FOR J=0TO16
32 INPUT#1,H(I,J)
34 NEXT
36 NEXT I
38 CLOSE 1
40 F1=0
42 PRINT"IS PRINT-OUT OF EXISTING MATRIX REQUIRED"
44 PRINT"IF YES TYPE 1 , IF NO TYPE 0"
46 INPUT F1
48 IF F1=1 THEN GOSUB900
50 PRINT"INPUT LINE NUMBER OF HEATING DATA TO BE AMENDED OR ADDED"
52 INPUT I
54 IF I<1 OR I>M THEN PRINT"INVALID" GOTO 50
56 PRINT"INPUT NEW DATA FOR HEAT AREA",I
58 PRINT
60 PRINT"ADD |ADD|FLOW|FLOW|FLOW|TD |AREAS TO BE"
62 PRINT"FLOW|TD |ZERO|CON |INDX|CON|SUBTRACTED"
64 PRINT"    |   |    |    |    |   |   |   |   |"
66 INPUT H(I,0),H(I,1),H(I,2),H(I,3),H(I,4),H(I,5),H(I,6),H(I,7),H(I,8)
68 PRINT
70 PRINT"INPUT APPORTIONMENT INFORMATION"
72 PRINT"UNIT|AP|UNIT|AP|UNIT|AP|UNIT|AP"
74 PRINT"    |  |    |  |    |  |    |"
76 INPUT H(I,9),H(I,10),H(I,11),H(I,12),H(I,13),H(I,14),H(I,15),H(I,16)
78 F2=0
80 PRINT"MORE AMENDMENTS?"
82 PRINT"IF YES TYPE 1 , IF NO TYPE 0"
84 INPUT F2
86 IF F2=1 GOTO 50
88 F3=0
```

Fig.(3.26) : LISTING OF THE PROGRAM USED FOR AMENDING THE MATRIX OF HEAT METERING DATA

```
90 PRINT"IS PRINT-OUT OF NEW MATRIX REQUIRED?"
92 PRINT"IF YES TYPE 1 , IF NO TYPE 0"
94 INPUT F3
96 IF F3=1 THEN GOSUB 900
98 PRINT"REWIND CASSETTE UNIT 2"
100 PRINT"THEN TYPE  CONT  & PRESS RETURN"
102 END
104 FOR C=0TO1
106 OPEN1,2,1,"MATRIX"
108 FOR I=0TOM
110 FOR J=0TO16
112 PRINT#1,H(I,J)
114 NEXT
116 NEXT I
118 CLOSE 1
120 PRINT"REWIND CASSETTE UNIT 2 READY FOR LOADING INTO MAIN PROGRAM"
122 END
900 OPEN2,4,2
902 PRINT#2
904 OPEN5,4,4
906 PRINT#5
908 OPEN3,4,0
910 PRINT#3,"MATRIX OF DATA FOR GEC WHETSTONE HEAT METERING"
912 PRINT#3
914 PRINT#3,"HEAT|ADDR|ADDR| FLOW | FLOW | FLOW | TD  | HEAT AREAS |
                                                        APPORTION"
916 PRINT#3,"AREA|FLOW| TD | ZERO |CONST |INDEX |CONST| SUBTRACTED |
                                                         UNIT|APP"
918 OPEN4,4,1
920 FOR I=0TOM
922 PRINT#3
924 P$=" ZZ   999  999    999 999999 999.99 99.99  ZZ  ZZ
                                                  ZZ   ZZ  Z.99"
926 PRINT#2,P$
927 X1=H(I,8):X2=H(I,9):X3=H(I,10)
928 PRINT#4,I,H(I,0),H(I,1),H(I,2),H(I,3),H(I,4),H(I,5),H(I,6),
                                              H(I,7),X1,X2,X3
930 P$="9

                                                       ZZ  Z.99"
932 PRINT#2,P$
934 FOR J=11TO15STEP2
936 PRINT#4,0,H(I,J),H(I,J+1)
938 NEXT J
940 NEXT I
942 CLOSE 2
944 CLOSE 3
946 CLOSE 4
948 CLOSE 5
950 RETURN
READY.
```

Fig.(3.26) continued : LISTING OF THE PROGRAM USED FOR AMENDING THE MATRIX OF HEAT METERING DATA

Fig.(3.27) : CENTRAL PROCESSOR SUB-SYSTEM IN THE BOILER HOUSE

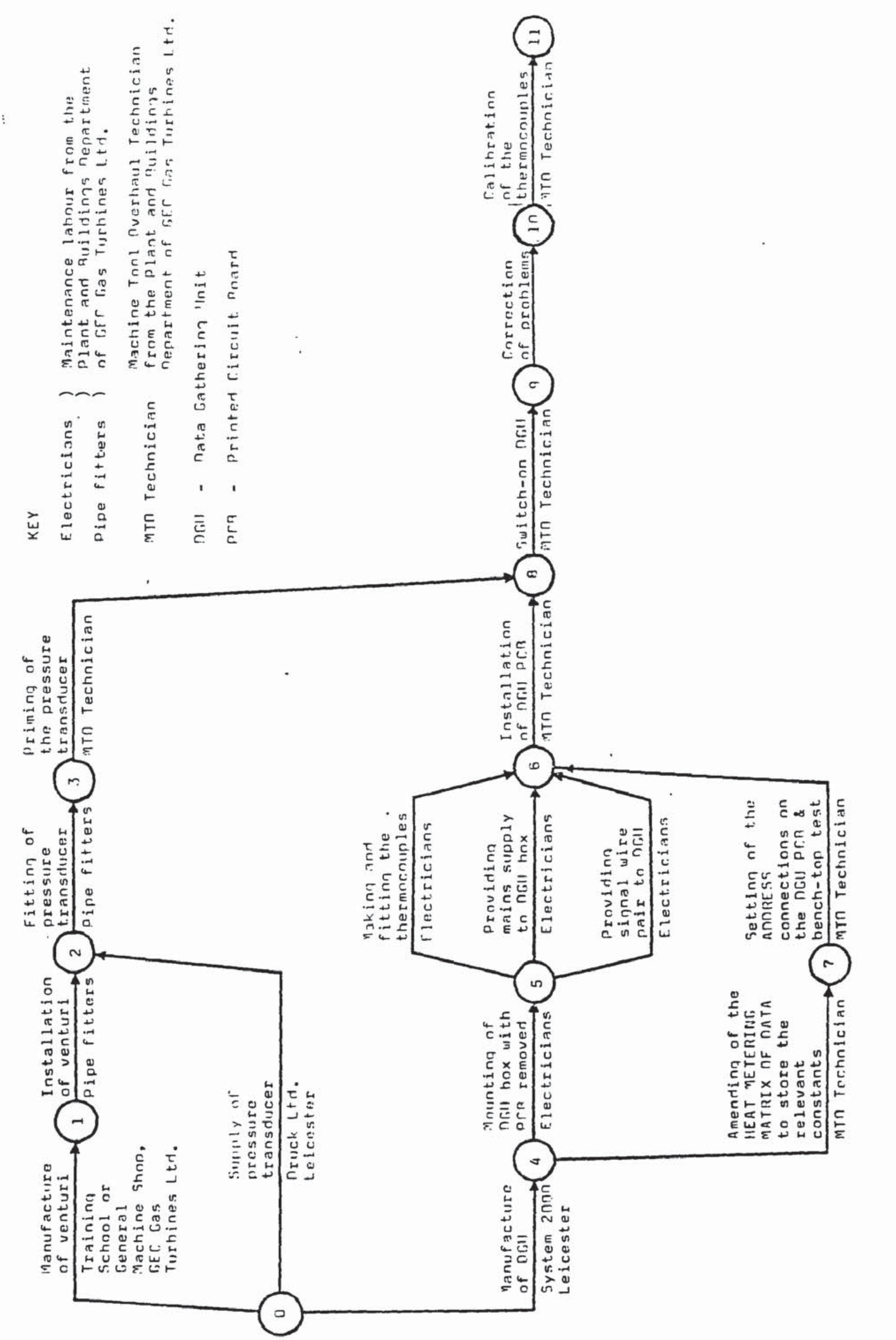


Fig.(3.28) : PATH DIAGRAM OF INSTALLATION AND COMMISSIONING ACTIVITIES

GEC WHETSTONE HEAT METERING

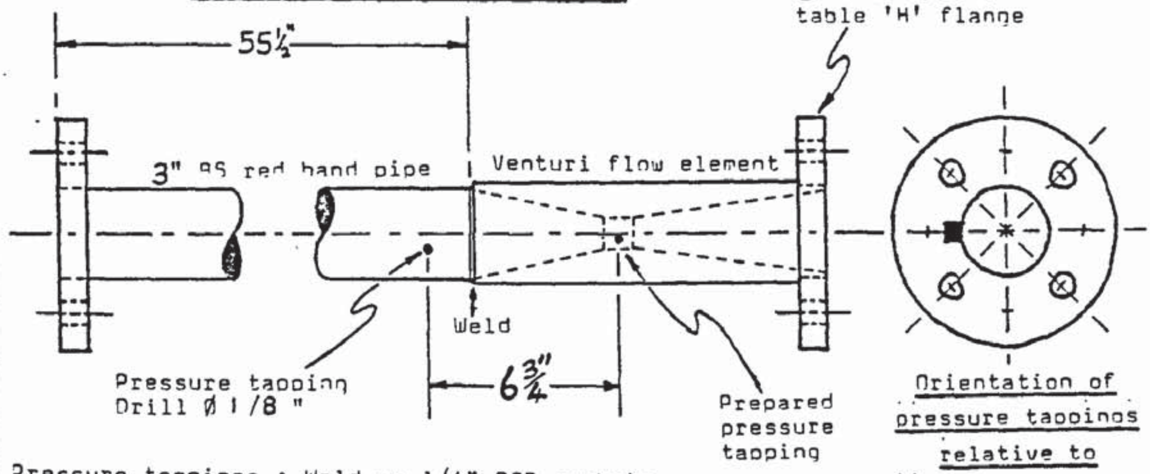
VENTURI INSTALLATION INSTRUCTION

LOCATION : BLOCK 56 BAY 7

DATE OF ISSUE : 27 JULY 1981

WORKING NUMBER : 388 EFA 6412

SHOP WORK : FABRICATION OF VENTURI SECTION

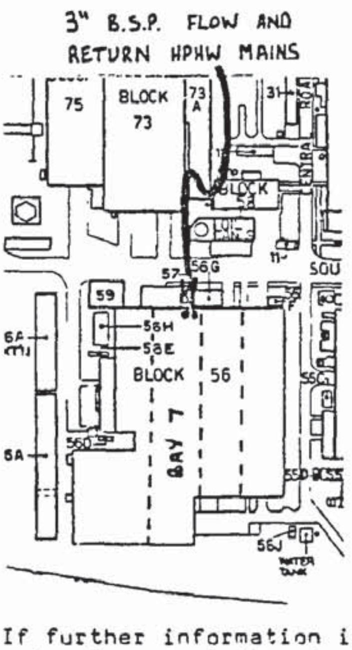


Pressure tappings : Weld on 1/4" BSP sockets

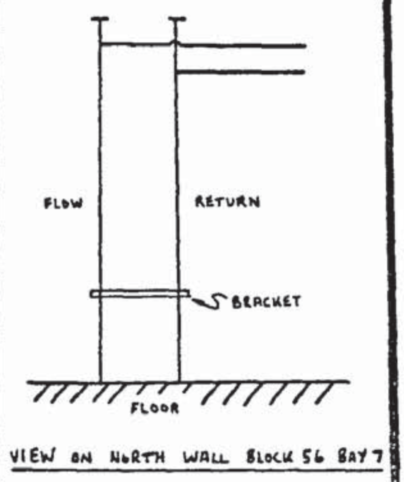
IN-SITU WORK : INSTALLATION DETAILS

Before starting any installation work obtain an HPHW Permit to Work from the Boiler House Foreman.

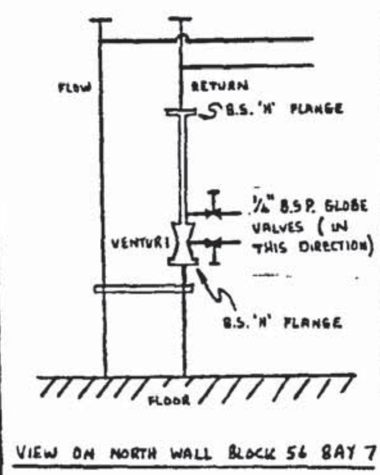
LOCATION



EXISTING



REQUIRED



If further information is required contact the Plant & Buildings Office or refer to an existing installation.

Fig.(3.29) : VENTURI INSTALLATION INSTRUCTION

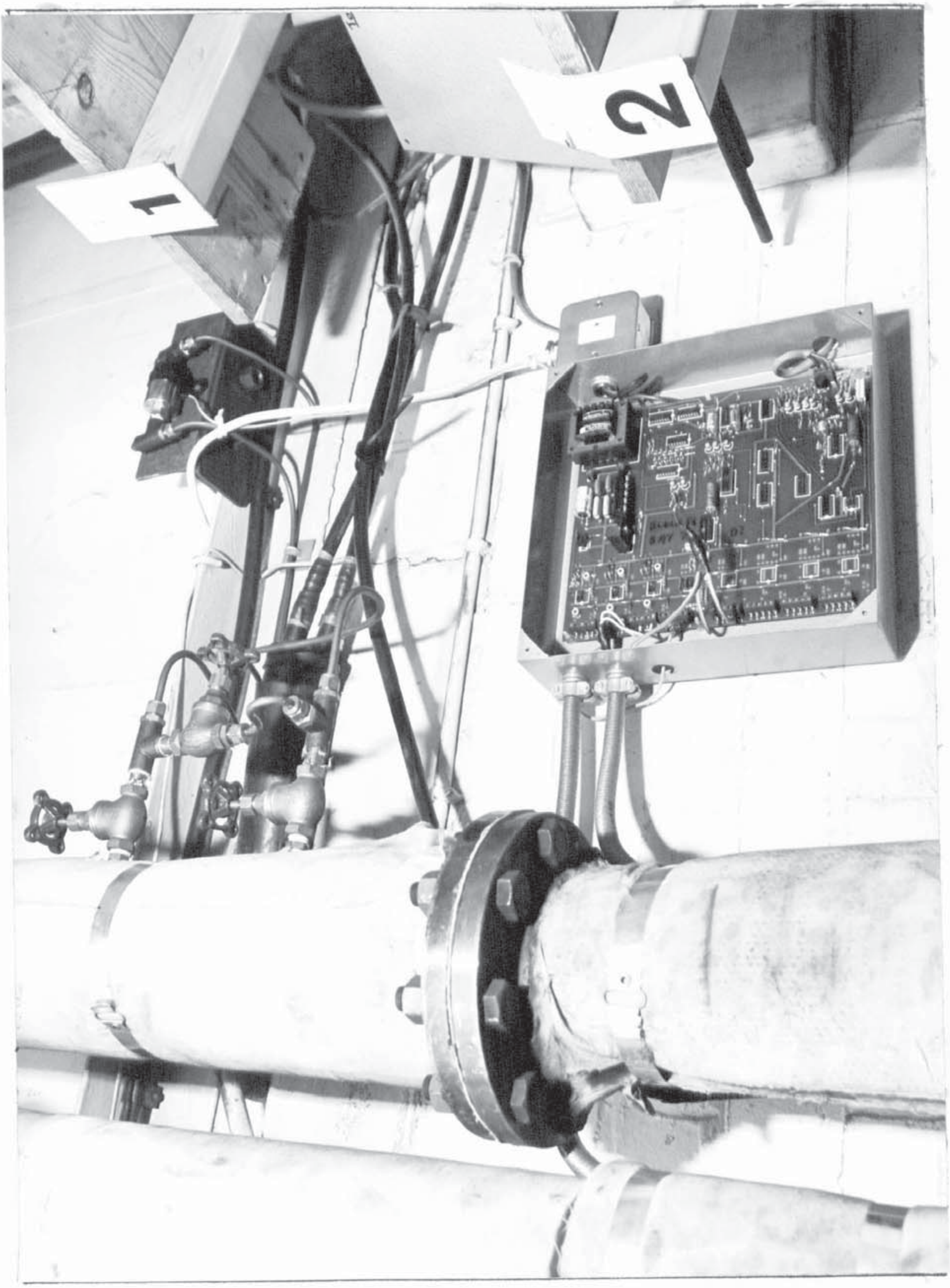


Fig.(3.30) : <u>DATA GATHERING UNIT (4-input) INSTALLED IN BLOCK 5A BAY 7</u>

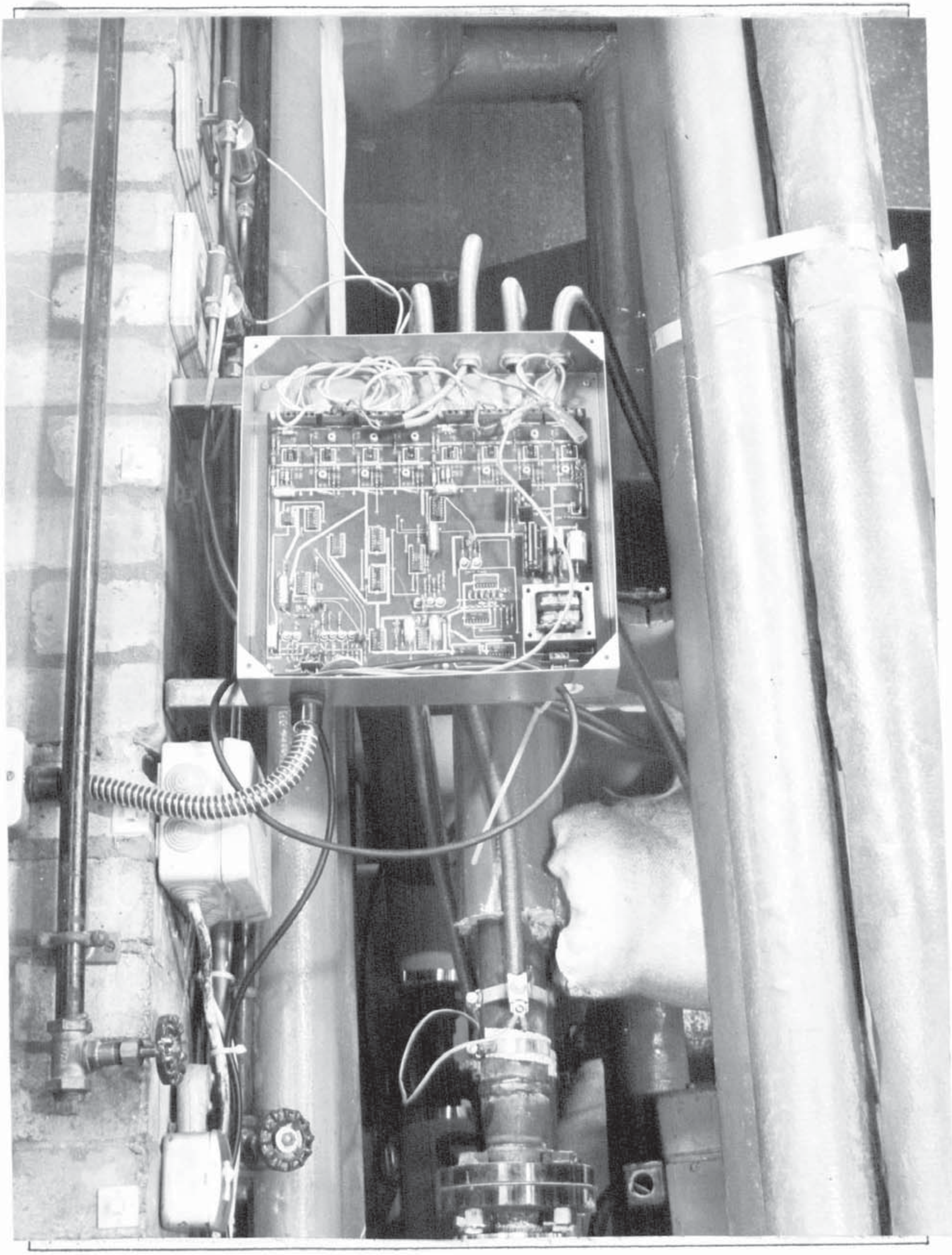


Fig.(3.31) : DATA GATHERING UNIT (8-input) INSTALLED IN BLOCK 59 PLANT ROOM

CHAPTER 4

DISCUSSION

4.1 Resumé of Work by the Author

Directly following completion of the installation of the heat metering system in January 1983, the author left the employment of GEC to join a practice of energy management consultants. As a result of these circumstances the author saw no operational period of monitoring and targetting using the heat metering system. The work involved in advancing to the installed heat metering system had therefore taken the full 3 year term under the IHD Scheme. In hindsight, the timespan of work on site was due firstly to the necessary attention to detail in the experimental and design phases (described in Sections 3.5 and 3.6) particularly with respect to electronics and software design, and secondly, from the high level of personal presence required in order to progress the installation and commissioning of 34 heat metering points across the site (described in Section 3.7). These two items of work took approximately one year each to complete.

The case for monitoring and targetting of heat consumption was primarily based on the reports by Rodrigues (16) that full savings from intermittently heating buildings (i.e. turning off the space heating when the buildings are not in use) at GEC Whetstone were not being achieved due to lack of line management commitment and poor attitudes of certain personnel. The underlying reason for lack of line management interest was made evident in Section 1.6.2 where it was estimated that energy costs in 1979/80 amounted to about 1% of value added in commercial operations on the site. Interest in energy efficiency should nevertheless be encouraged because this proportion is set to increase in future years as described briefly in Section 1.1. Also the site energy bill at £0.75M in 1979/80 is to within an order of magnitude the same as the trading profit and therefore energy savings are somewhat more significant in profitability terms.

Lack of interest in energy efficiency in low energy intensive sites such as GEC Whetstone (i.e. where energy cost is 1% or 2% of site value added) manifests itself in the so called 'barriers to energy efficiency' found in published literature, Department of Energy (4) Low energy intensity energy user covers a wide variety of consumers including non-energy intensive industry, transport, domestic and commercial sectors. As shown in Section 1.4, these accounted for 84% of gross energy consumption in the UK in 1983. Use in space conditioning for buildings across the sectors is a high proportion representing some 40% - 50% of the gross UK energy consumption with industrial and commercial buildings taking 10% - 20%. It was therefore concluded in Section 1.4 that although buildings are a low intensity use of energy, their numbers and total amount of energy used makes them a very important area for energy conservation work and whatever exists of the so called 'barriers to energy efficiency' must be removed.

The lack of line management commitment and poor attitudes of personnel at GEC Whetstone to the relatively newly installed intermittent heating strategy was a specific symptom of barriers to energy efficiency where, in this particular instance, energy and monetary loss could be quantified. In Section 1.7, it was estimated from monitoring work undertaken by Rodrigues in four buildings that savings of between 5% and 10% could be achieved on space heating consumption equating to 8300 GJ - 16600 GJ valued at approximately £13800 and £27600 respectively at 1979/80 prices.

In view of the problem at GEC Whetstone being one of involvement and motivation of line management and personnel the technique known as monitoring and targetting was put forward as the solution. This is a management method in which line management at all levels budget (target) and account for (monitor) energy use in a similar manner as they do for most production related resources such as manpower, raw materials etc.

Taking the minimum saving estimated from Rodrigues monitoring work in four buildings, expenditure on installation of monitoring and targetting of heat consumption amounting to £69000 could be justified at the GEC payback criterion of 5 years.

Chapter 3 describes how the author devised a heat metering system comprising 34 metering points for a capital expenditure of £40620 which is, as is shown in Section 3.4, about half the cost of the cheapest commercially available system. The main methods of achieving the low cost were :

(1) Use of apprentice labour and machine idle time in producing venturi flow meters for the system.

(2) The use of spare night cut-off cabling to transmit all data to a central processor thereby eliminating costly distributed electronic processing and reducing data transmission costs.

In Chapter 2, the author reviews energy management theory and practice generally and at GEC Whetstone specifically. The review shows energy conservation work at GEC to be well advanced and that monitoring and targetting is one of the few and certainly the most important conceptual advance that could be made The author does however express the opinion that although monitoring and targetting at a late stage in an energy management programme serves to maintain the performance of energy efficiency measures already installed; had it been installed earlier it would have catalysed capital investment resulting in faster implementation and therefore higher accumulation of savings. discussed further in Section 4.3.

4.2 Use of Heat Metering Data in Monitoring and Targetting at GEC Whetstone

As explained in Section 3.2, the breakdown for heat metering was based on buildings as the energy cost centres. The aim and intention was therefore to present the managing body in each building with heat targets expressed in both units of energy and money followed by periodic presentation of bills based on metered heat consumptions. There exists in this a very basic form of incentive for the manager in that the expenditure allowance for energy in his budget, which beforehand was lumped into his overhead account, has to stand on its own account. If he overspends his budget, the situation is liable to investigation with his own competence coming into question. Whilst it is clearly unrealistically drastic to discipline a manager for poor energy efficiency at the present time, where energy costs probably make up 1% of his operational costs, an alternative approach of offering a performance related bonus to his salary might be a possibility,

Targets

Target heat consumption for the buildings at GEC Whetstone could be derived in one of two ways, either theoretically or by monitoring.

Theoretical Targets

Theoretical targets for heat consumption could be calculated using one of the models of building thermal behaviour described in Section 2.8, inputting such parameters in fabric areas, 'U' values, estimated air change rates, statutory internal temperatures and degree day information. Theoretical targets could serve to show the best that could be achieved but these are likely to be so far removed from current practical consumptions that they would be useless as 'incentive targets'. The main reason for the models being inaccurate is predominantly due to the value input for air change rate. In the author's experience actual air change rates are nearly always higher than the statutory minimum. The statutory minimum figures therefore give low targets which of course are worthwhile achieving but are usually too big a step change to act as interim incentives to gradual acceptance of energy efficiency measures. Alternatively, measurement of existing air change rate in a building is possible and is achieved by heat balance taking into account all heat gains and losses.

Clearly this does require heat metering to quantify the gain from the space heating system and is therefore less of a theoretical target and more a monitored target.

Monitored Targets

Monitored targets are derived using the heat metering system itself to generate the thermal characteristic of a building. This is achieved by recording heat consumption over a number of months against production hours worked and degree days experienced to form a base empirical relationship between existing heat requirements building usage and climatic conditions. Prediction of heat consumption for a target month is calculated by taking anticipated production hours and nominal degree days for the month in question (the average degree days experienced historically in previous years) and then using the empirical relationship to forecast heat usage. The target heat consumption itself is the predicted heat usage minus energy savings estimated for measures implemented minus a small percentage, say arbitrarily 5% annually, as an incentive to personnel for good housekeeping.

Heat Consumption Targets for GEC Whetstone Buildings

The aim of monitoring and targetting of heat consumption at GEC Whetstone, as described in this thesis, was to

motivate line management and personnel towards a commitment and acceptance of intermittent heating in office and factory buildings. It was intended therefore for the targets to be set at a level which could be attained by a good standard of co-operation and support for the intermittent heating strategy. The targets were to be derived by monitoring buildings over a period of some months with close supervision by boiler house personnel to ensure the building was efficiently operated, in particular, making sure windows were closed overnight and radiators were not covered (Section 1.7).
The target so produced should reflect Rodrigues' (16) observations presumably with the 5% - 10% savings relative to unsupervised buildings which he suggested were possible, therefore giving payback on the installation of the heat metering system in accordance with the calculation shown in Section 1.8.

Managing Bodies

As explained in Section 2.11.2, monitoring and targetting permeates the whole of management structure within a company of industrial site from senior management to a line management level with immediate responsibility for the energy cost centres. In the case of monitoring and targetting of space heating consumption at GEC Whetstone, this meant the preparation of information for both senior management of each of the six tenant subsidiaries and their line management in individual buildings. For this reason, heat meters readings on the computer print-out were grouped together under the headings of each tenant subsidiary as shown in Appendix 5 so that senior management of each unit could be presented with the total heat consumption of the buildings that they occupy.

As explained in Section 3.2, the managing body in each building which were intended to receive the monitoring and targetting information would not necessarily be just one line manager, rather a committee of managers who jointly used the building. A rule to be applied in deciding whether the managing body should be one person or a committee is that the managing body must work in the building and not have office accommodation remote from it (Section 3.2). Thus if a building could be made the responsibility of one manager but his office is in a remote office block then the managing body should comprise of his subordinates who actually work in the building formed as an 'energy' committee with himself as the head. In some buildings at GEC Whetstone (refer to Fig. (1.2)), different tenant subsidiaries occupy parts of the same building. In these instances the role of the energy committee formed from line management of the respective companies is essential if all are to gain from energy savings.

4.3 Future Use of Heat Metering Information and Monitoring and Targetting

Gaining line management commitment and support for good housekeeping measures with respect to intermittent heating of buildings is clearly a very specific objective for a monitoring and targetting exercise requiring only the simplest of actions to be successful. Although this basis for monitoring and targetting may appear very narrow there are two good reasons for it.

(1) Capital expenditure on a heat metering system had to be supported by hard evidence of savings from some source before GEC management would give authorisation. The limited monitoring by Rodrigues (16) in 4 buildings and his observations described in Section 1.7 gave the initial evidence that savings of the level needed to justify capital expenditure on a heat metering system could be made. This is not to say that there are no other savings that may result from monitoring and targetting, just that this one source of savings could support the level of expenditure required for a heat metering system.

(2) The monitoring and targetting information was to be directed at a cross section of line management who would have differing levels of understanding relating

to energy efficiency. The first step therefore is best kept simple.

As explained in Section 2.11.2, from Swallow (51), monitoring and targetting can involve two active cycles, illustrated in Fig. (2.2), one concerned with the improvement of energy efficiency through capital expenditure and implementation of energy saving measures and the other with maintaining energy efficiency. Clearly the use of monitoring and targetting to ensure the effectiveness of the intermittent heating strategy at GEC Whetstone is a maintenance type function.

The performance of monitoring and targetting in terms of generating energy savings could be enhanced if it were accepted as a means of supporting capital expenditure. As stated in Section 2.12, energy saving measures which had been proven during Rodrigues study were replicated in other applications across the site by site civil, mechanical and electrical engineers. One programme of replication work, the thermal insulation of buildings, was proceeding very slowly and this could be catalysed through extension of monitoring and targetting and making a capital allowance available through the scheme to be spent by the managing body of each energy cost centre (i.e. the energy committee for each building).

Once a line manager is presented with monitoring and targetting information, an energy bill and a capital allowance in his budget he at least becomes aware that there is a problem to be solved and that he is meant to play an active part. At this stage then, the drive for energy saving is down to the individual line manager at the 'end of the line' and by crude inference the barriers to energy efficiency which are organisational in nature (listed in Section 1.7, Items (1), (2), (3), (4), (6) and (7)) are surmounted. No doubt, though, in the case of item (1) relating to the tenant/landlord arrangement at GEC Whetstone, there would be some hard 'commercial' bargaining as to whether tenant or landlord's capital should be spent but at least heat metering information makes the bargaining possible through being able to reconcile capital and running costs.

The remaining barrier to energy saving is the level of ability that a line manager has for implementing energy saving measures (Section 1.7, Item (5)). The natural answer is to have a central energy efficiency service on the site having a 3 part brief:

(1) To provide technical assistance to line management to implement energy saving measures in the building. This service to be provided at the request of a line manager and paid for from his budget allowance.

(2) To set standards of uniformity for like measures across the site (e.g. Appearance of building insulation) and to co-ordinate line managers who plan to implement similar measures.

(3) To have no 'above board' sources of capital. All capital for energy saving measures is to be derived via line management budget allowances.

This third item is the complete reverse of the current arrangement, and that which has existed at GEC Whetstone for the last 9 years, where the Estates Department handles the capital sums with line management paying a running cost. Essentially the author is advocating that capital resources for energy efficinncy measures should be channelled to line management who, in the light of their metered energy usage and cost billed, their energy targets and advice from the central energy efficiency service; will 'vote with their capital allowance'as to the measure that would best benefit them. The motivational strengths of this arrangement to line management would appear very strong in terms reducing energy consumption relative to their productivity and having firm commitment to energy saving.

4.4 Final Costs of the Installed Heat Metering System

The final costs of the various elements to the heat metering system were as shown below. Where costs were spread over a number of years these have been adjusted to equivalent 1979/80 prices.

Item	Cost (£)
Central processor	1100
Sub-contracted electronics	4695
Venturis	580
Pressure transducers	10795
Thermocouples	410
Installation man time	23040
Capital cost	40620
Estimated cost of employing the author for 3 years less SERC grant	12000
Total outlay	52620
Ongoing operating and maintenance cost per annum	3000

With a total outlay of £52620 it can be concluded that it was possible for the author to construct a heat metering system for the GEC Whetstone site for less than the limited £69000 available, shown in Section 1.8, and despite the ongoing operating and maintenance costs, a 5% saving in space heating consumption is all that is required to give the criterion payback of 5 years.

i.e. Saving of 5% in space heating fuel consumption
in 1979/80, from Section 1.8
= £13800

Less operating and maintenance costs of £3000
= £10800

Total outlay = £52620

Payback = $\frac{52620}{10800}$ = 4.9 years

Note: Operating and maintenance costs include the costs of forwarding heat metering data to line managers and the employment of a technician part-time to maintain the system.

In view of the heat metering system having a low capital cost compared with commerical systems (Section 3.4.2), it can be concluded that the use of apprentice labour and machine idle time to produce venturis, the use of central processing and data transmission via spare cabling already installed on the site (Section 3.4.3) were beneficial.

4.5 Potential Energy Savings to Industry from Replication of Monitoring and Targetting of Heat Consumption as at GEC Whetstone

If the 5% to 10% savings in space heating consumption suggested in Section 1.7 is achieved at GEC Whetstone through motivating line management and personnel to maintain buildings in conditions for optimum intermittent heating, then assuming similar circumstances in all UK industrial buildings the overall benefit is as follows:

Energy supplied to industry during 1983 on a heat supplied basis (from Table (1.3))
= 1479 PJ

Industrial buildings consume 40% of energy supplied to industry (from Section 1.4)
= 592 PJ

Saving of 5% = 30 PJ

Saving of 10% = 60 PJ

Direct replication of the author's work, that is using multi-point heat metering system served by a central computer, is a possibility only on the large multi-building industrial sites. In the UK half of industrial energy consumption is accounted for by 14 large companies (Department of Energy, (25)) who typically own the larger multi-building sites. Thus overall savings nearer the lower of the two above figures would be the probable benefits of direct replication of the author's work.

CHAPTER 5

CONCLUSION

Against the background of depleting world energy resources there is the wide acceptance of the need to conserve energy. A problem besetting the growth of energy conservation in the UK is that 84% of gross energy consumption (in 1983) is used in a low intensity manner in energy non-intensive industry, transport, domestic and commercial sectors and here organisation for the management of energy is under-developed. This is because the would be responsibility for energy is spread over a large number of personnel who each see only small energy costs (c.f. Energy intensive industry using 16% of gross UK consumption where energy management is relatively well developed). For there to be a growth in energy conservation for the UK as a whole, energy management for the non energy intensive users has to be developed.

In relation to this need, the author has made a specific application of an energy management technique known widely as monitoring and targetting for use at GEC Whetstone which is a typical non energy intensive industrial site. The application is specifically designed to gain commitment and to motivate line management and personnel into acceptance of change from previous continuous heating to intermittent heating and furthermore to play an active part in its operational effectiveness. Further advances using the technique are possible as discussed in Section 4.3.

Monitoring and targetting of heat requires a heat metering system at an acceptable and justifyable cost. The author designed and installed such a system at a relatively low cost against allowable capital budget and against the cost of commercially available systems. Instrumental in achieving this was the manufacture of venturi flow meters on otherwise idle machine tools and by apprentices, the use of central data processing and use of spare cabling already installed around the site for transmission of data.

In undertaking this work the following specific conclusions were reached:

On the preparation of the case for heat metering for monitoring and targetting:

(1) GEC Whetstone is a non energy intensive user. Site energy costs in 1979/80 accounted for about 1% of site value added (Section 1.6.2).

(2) Energy supplies to the site in 1979/80 were as follows (Section 1.6.2):

Fuel	GJ	Cost (£)
Natural gas	155900	256180
Heavy fuel oil	10200	20260
Electricity	57200	375380
Gas oil	22700	88800
TOTAL	246000	740620

(3) Provision of space heating accounts for 90% of natural gas and heavy fuel oil consumption and is an indirect or overhead energy use.

Electricity usage is 38% direct and 62% indirect.

Gas oil is used for turbine testing; a direct use.

(from Section 2.4).

(4) GEC Whetstone had an established energy conservation programme managed by the Estates Division. The programme was very advanced in terms of having rigorously investigated and applied energy conservation measures at least for energy intensive items of plant (Chapter 2). This programme had been supported by research input from Rodrigues (16), an IHD student during the year 1976-1979 prior to the author's work.

(5) There was observed malpractice on the part of line management and personnel in relation to the effectiveness of intermittent heating (Section 1.7). An assessment of the cost of the malpractice was possible from data generated by Rodrigues (16).

(6) The cost of non commitment of line management and poor attitudes of personnel was estimated to cost 5% - 10% of space heating consumption amounting to between 8300 GJ and 16600 GJ valued in 1979/80 at £13800 and £27600 respectively (Section 1.7).

(7) This level of saving could justify capital expenditure of up to £69000 on a heat metering system at the GEC payback criterion of 5 years.

<u>On the design of a heat metering system for the GEC Whetstone site:</u>

(8) The energy cost centres for metering of heat consumption should be, as far as is possible, on a building by building basis. This gave rise to 34 heat metering points at GEC Whetstone (Section 3.2).

(9) The device for flow metering within heat meters had to have a large bore element such as an orifice plate or venturi because solids and chemical additives in the HPHW system would cause delicate instruments

with moving parts such as turbine flow meters to seize. Orifice plates were further unacceptable because of their high net head loss. Venturi flow elements were the only possibility within the bounds of acceptable price (Section 3.4.1).

(10) A commercially available system for heat metering at GEC Whetstone could not be found for a cost of £69000 (Section 3.4.2).

(11) The author designed and subsequently installed an in-house developed heat metering system for a cost of £52620 (Section 4.4).

Venturis for the system were produced on otherwise idle machine tools and by apprentices for about £20 each, i.e. negligible cost.

Costs of computation of heat quantity were reduced below commercially equivalent prices by combination of use of central processing and use of spare cabling already installed on the site for data transmission (See following Items (13) and (14)).

(12) Tests carried out on an in-house manufactured venturi showed measured flow rate to be within the calculated BS 1042 tolerance of ±1.77% (relative to measured flow) for the turndown range of 3:1

(Section 3.5.1) which more than covers the 70%-100% flow rate range experienced in HPHW circuits at GEC Whetstone (Section 3.8.1).

(13) Use of spare night cut-off cabling for data transmission produced capital savings of around £20000 to the use of a central processing facility (Section 3.4.3). This eliminated the penalty of data cabling for central processing which would otherwise be in the favour of conventional discrete heat meters each with their own readout. Central processing enables the centralisation of complicated computation leading to the low relative cost of the heat metering system.

(14) Central intelligence architecture as opposed to distributed intelligence had to be adopted in order that it was constructionally simple enough for in-house production and also competitive against the commercial scale, furthermore instrumental in yielding the acceptable price of £52620 for the system (Section 3.4.3).

(15) The estimated accuracy calculated for individual heat meters is (Section 3.8.1):

±2.5% of measured heat over a heating season

±2.7% of measured heat over a single day

These levels of accuracy are good enough for monitoring and targetting.

(16) Limited checks on the overall accuracy of the system show similar order of error (Section 3.8.2).

(17) There are no conclusions as to the energy saving effects of involving line management and personnel through monitoring and targetting because the work involved in preparation, design and installation of the heat metering system took the full 3 years of the author's IHD postgraduate term.

(18) Future work on the introduction of new energy saving technology at GEC Whetstone is limited for the time being. However, replication work, particularly building insulation, could be speeded up. The motivation for this could be brought about through the scheme of monitoring and targetting of heat consumption as described in Section 4.3.

<u>On the wider UK scale:</u>

(19) Industrial buildings consume some 592 PJ annually which requires about 10% of UK gross annual energy consumption (Section 4.5).

(20) Over all types of industrial company and buildings a 5% saving from simple involvement of line management and personnel through monitoring and targetting of heat consumption (i.e. direct replication of the author's work) would be 30 PJ. The approximate value of this quantity of energy at today's (1985) prices is £100M.

(21) Probably the most significant benefit to come of monitoring and targetting would be the speeding up of capital investment in energy conservation as described in Section 4.4 which would surely be an advantage as industry progresses, for the time being, into a future of increasingly more costly energy supply.

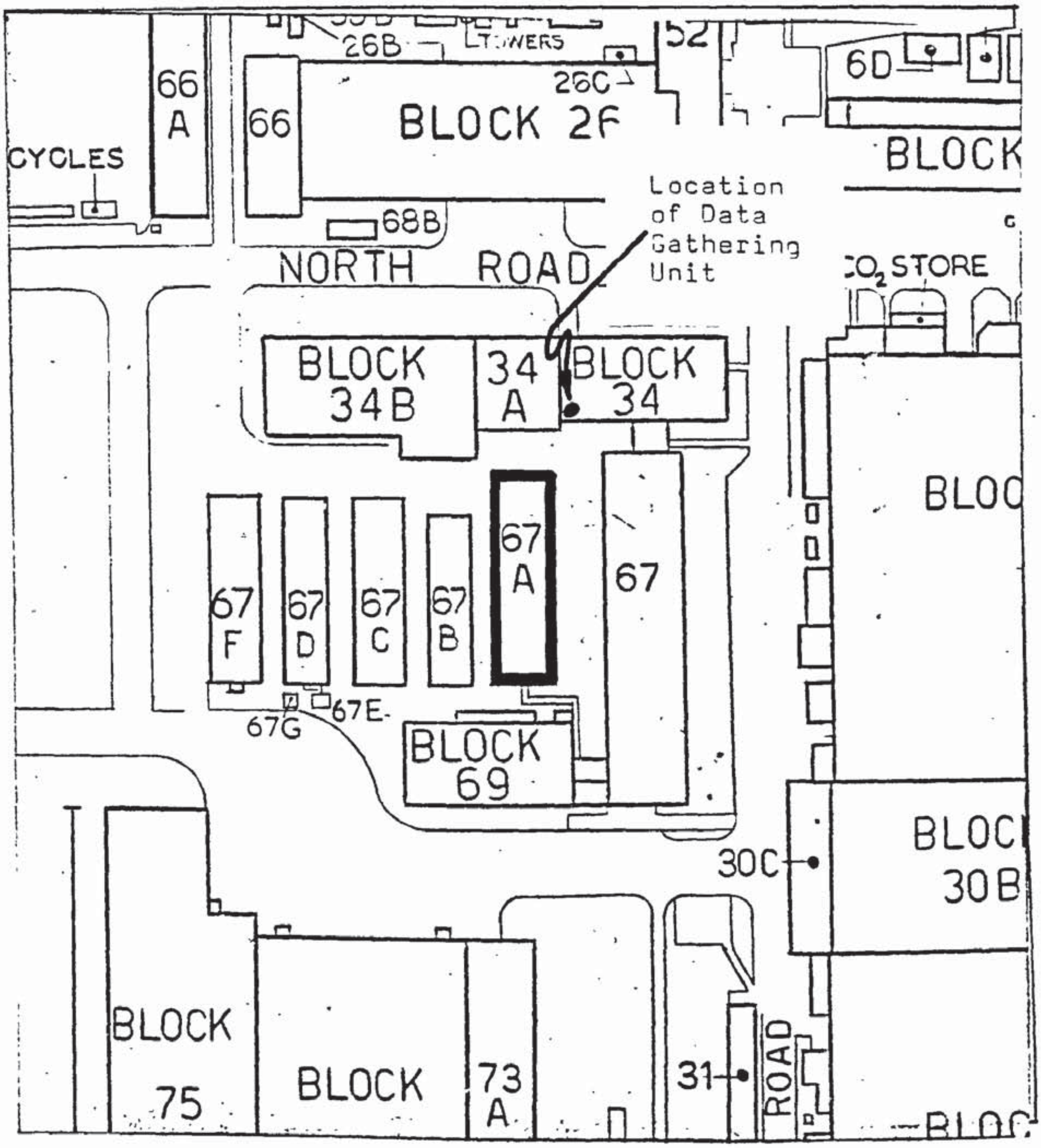
APPENDIX 1

GEC WHETSTONE HEATING AREAS,

LOCATION OF DATA GATHERING UNITS

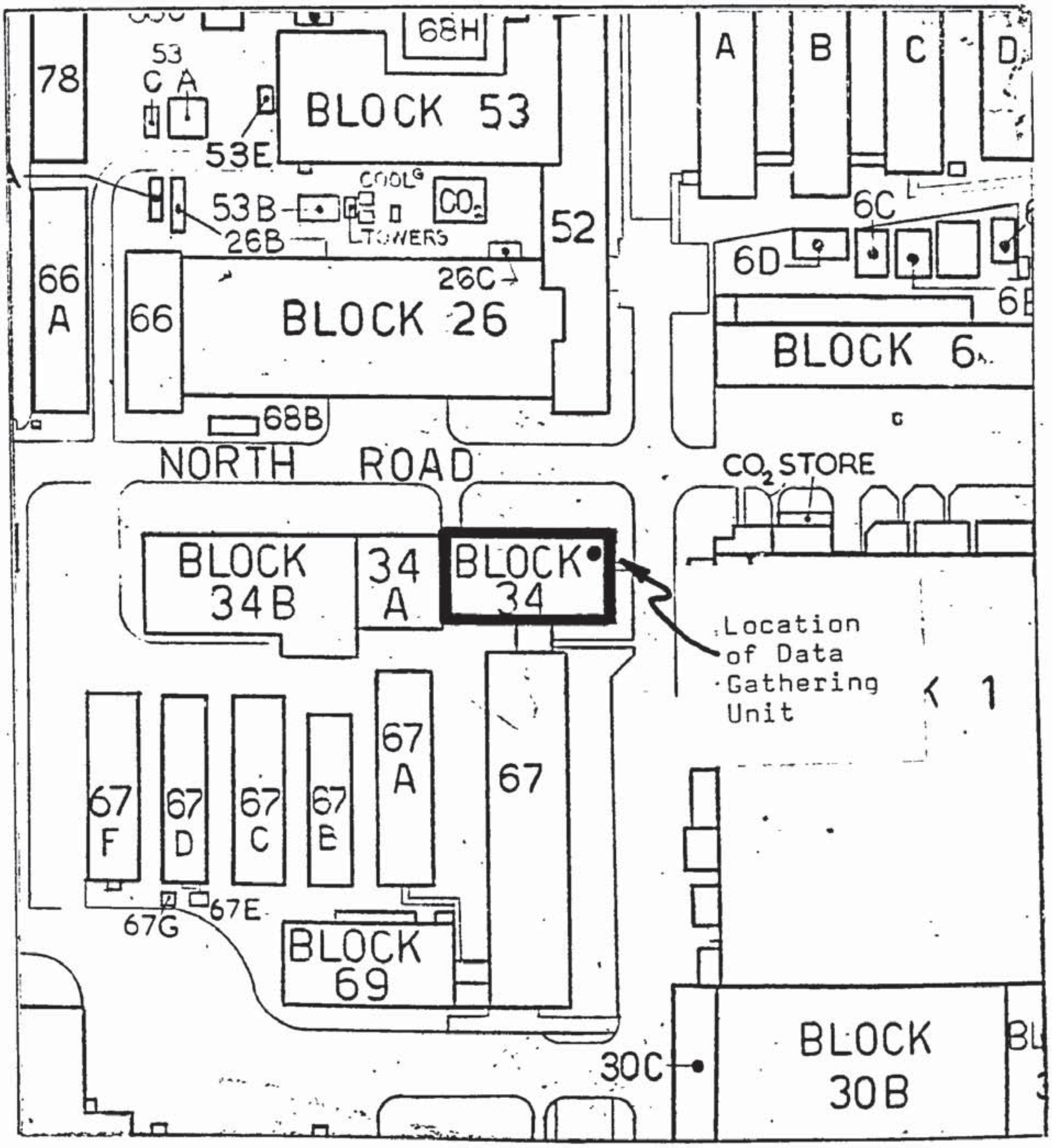
AND

DIRECTORY OF INPUTS



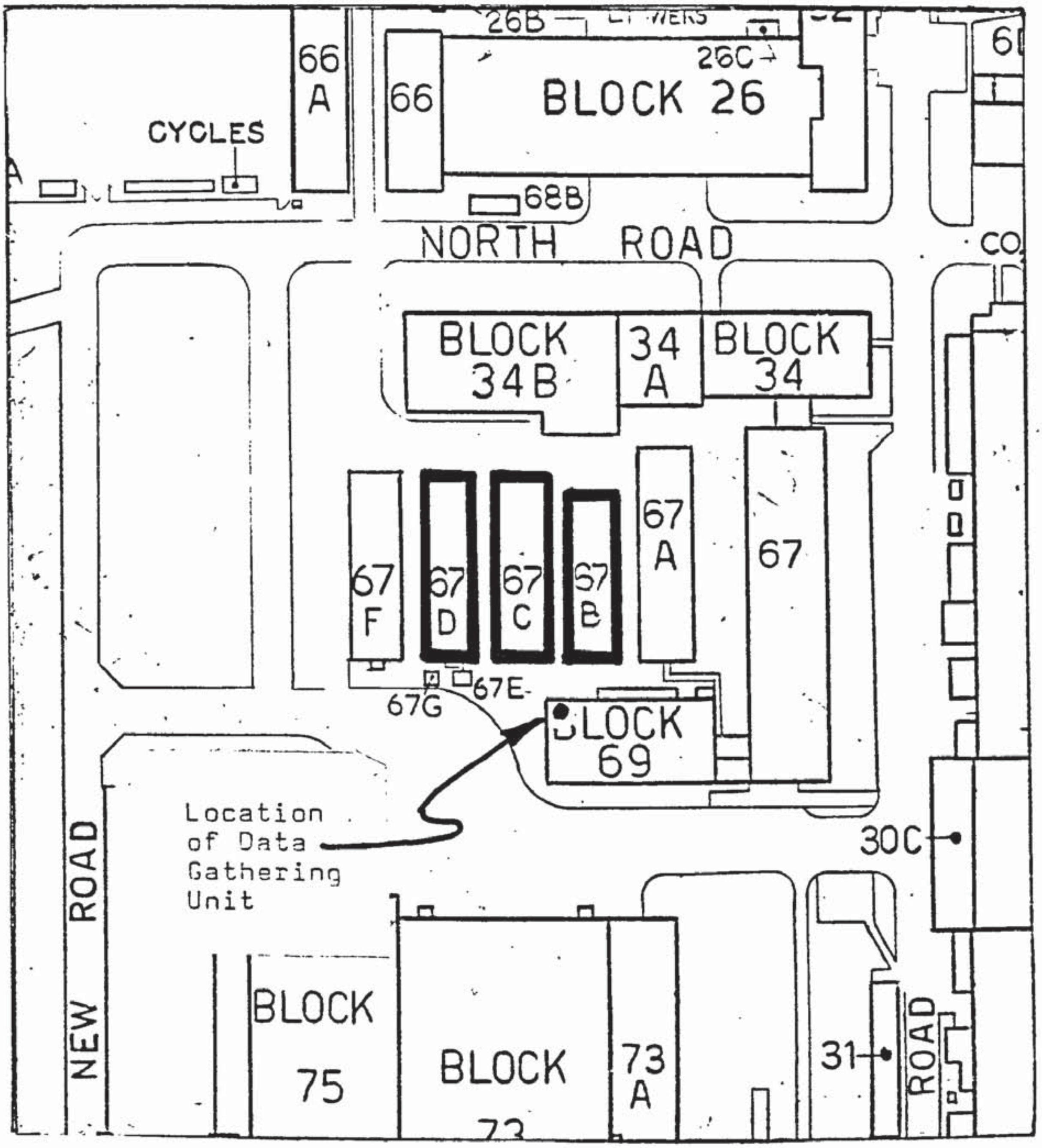
HEATING AREA : 01

Data gathering unit input	System input	Function
0	56	
1	57	
2	58	
3	59	
4	60	
5	61	
6	62	Tc
7	63	FLOW



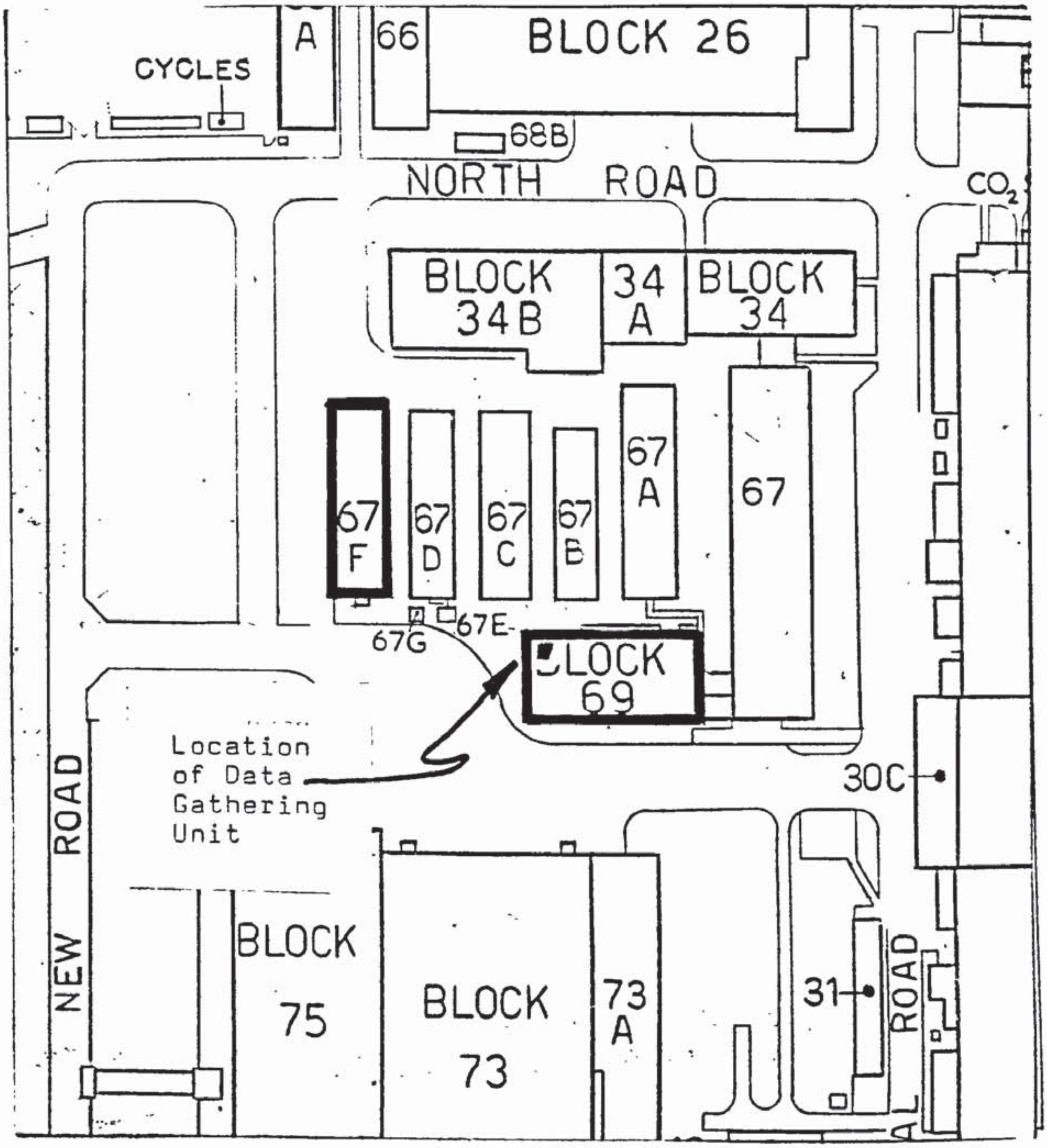
HEATING AREA : 02

Data gathering unit input	System input	Function
0	20	T_D
1	21	
2	22	
3	23	FLOW (INCLUDES HEATING AREA 01)
4		
5		
6		
7		



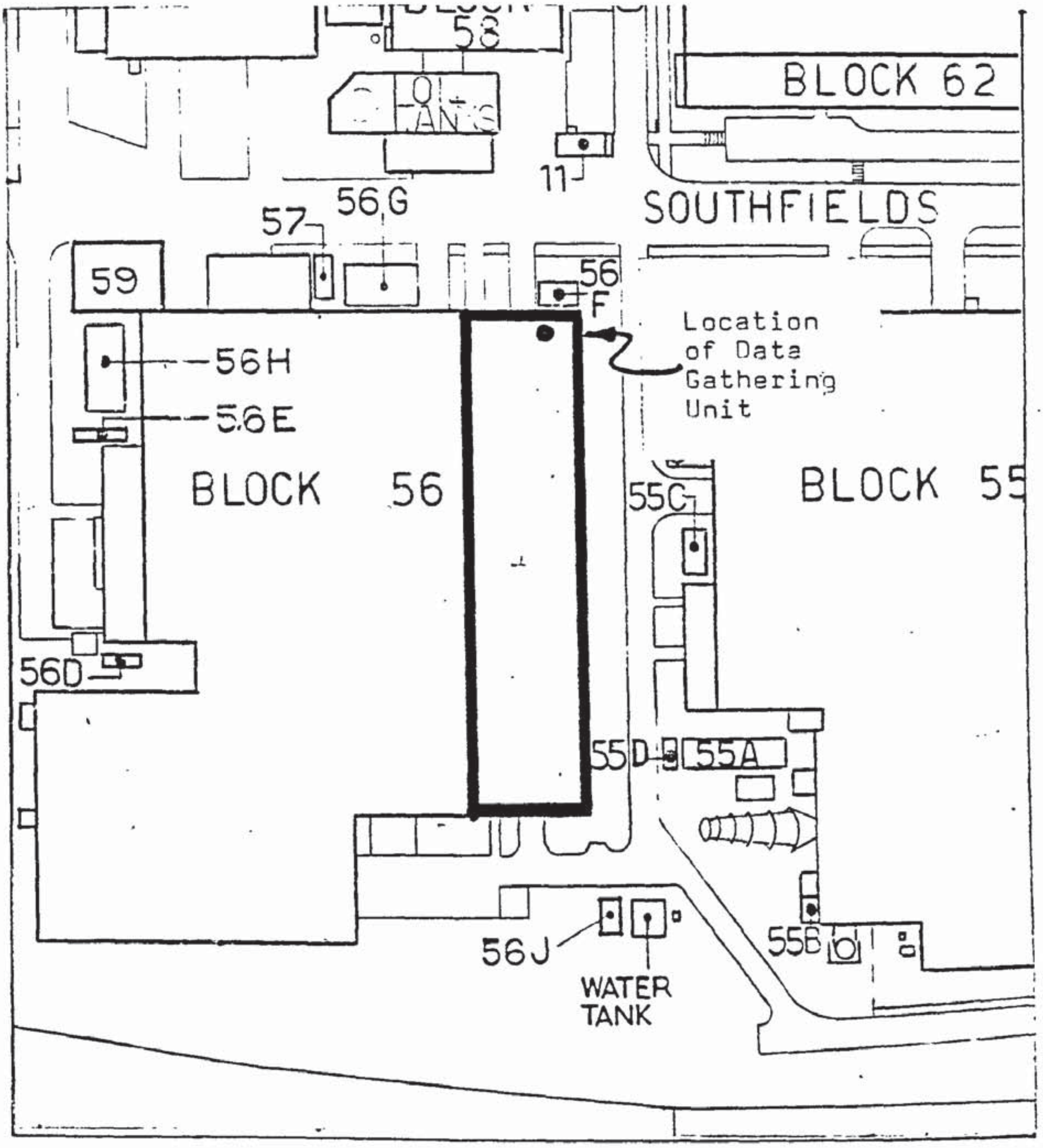
HEATING AREA : 03

Data gathering unit input	System input	Function
0	24	
1	25	
2	26	T_D
3	27	FLOW
4	28	
5	29	
6	30	
7	31	



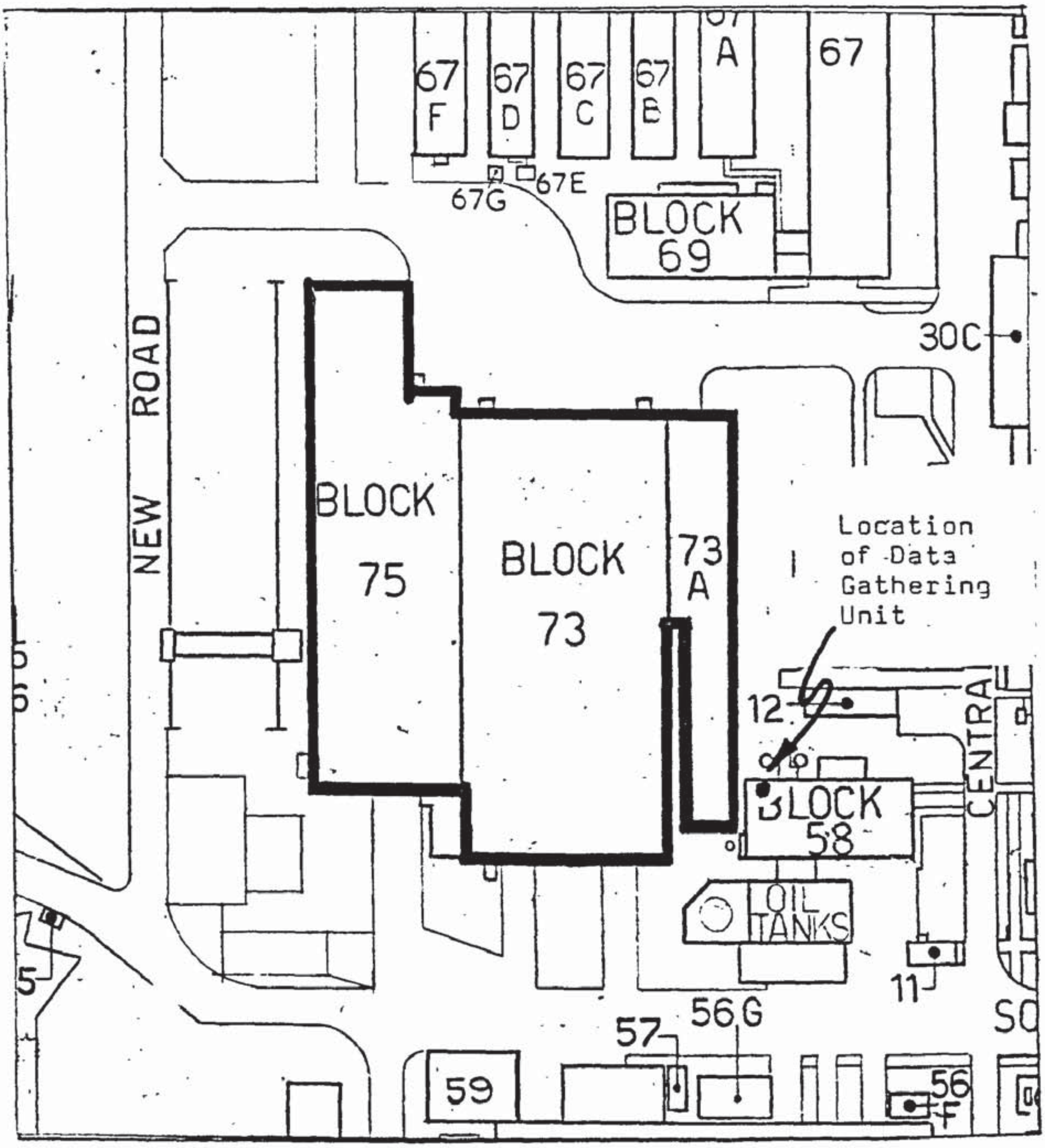
HEATING AREA : 04

Data gathering unit input	System input	Function
0	24	
1	25	
2	26	
3	27	
4	28	
5	29	
6	30	T_D
7	31	FLOW



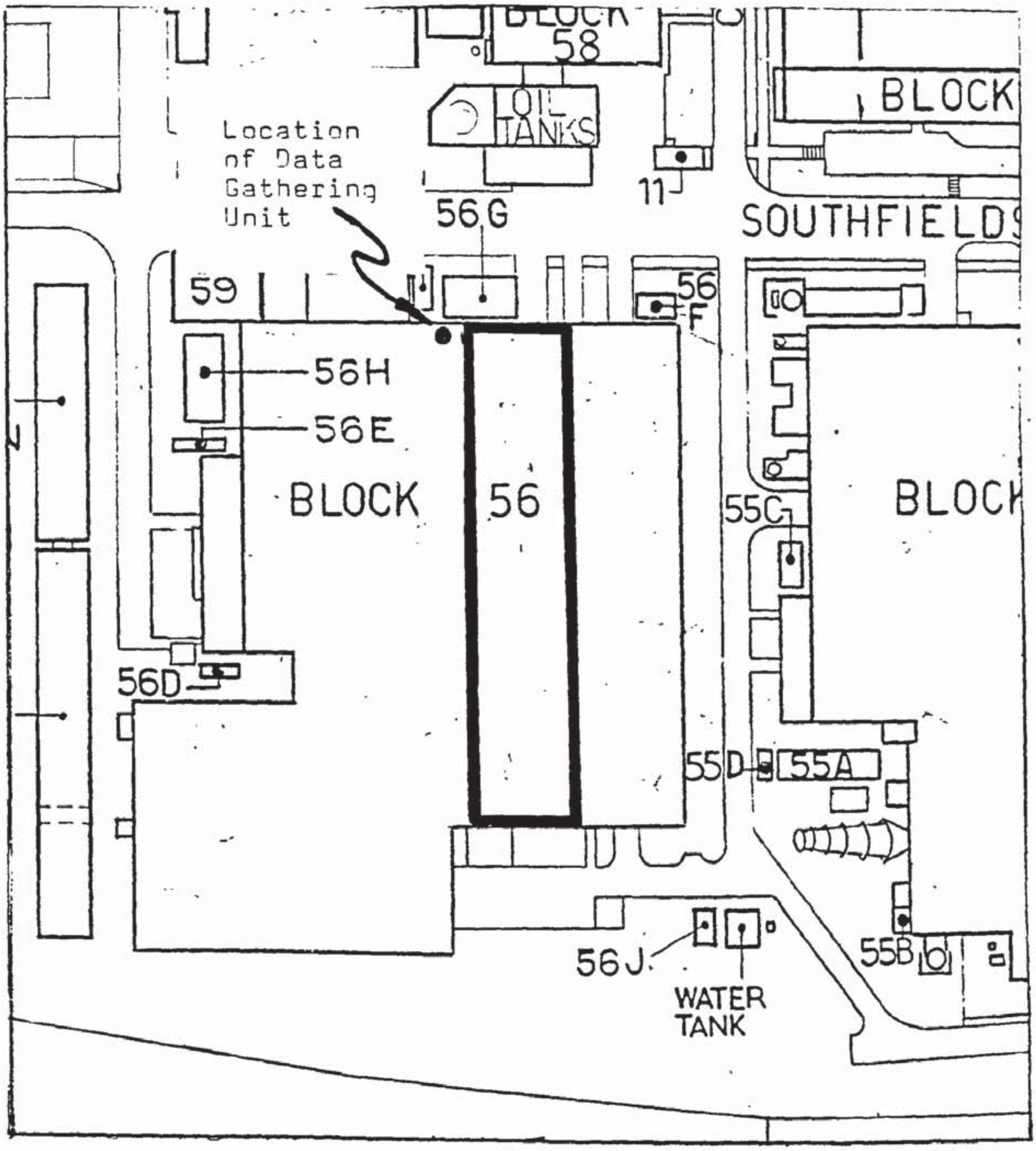
HEATING AREA : 05

Data gathering unit input	System input	Function
0	32	
1	33	
2	34	T_D
3	35	FLOW
4		
5		
6		
7		



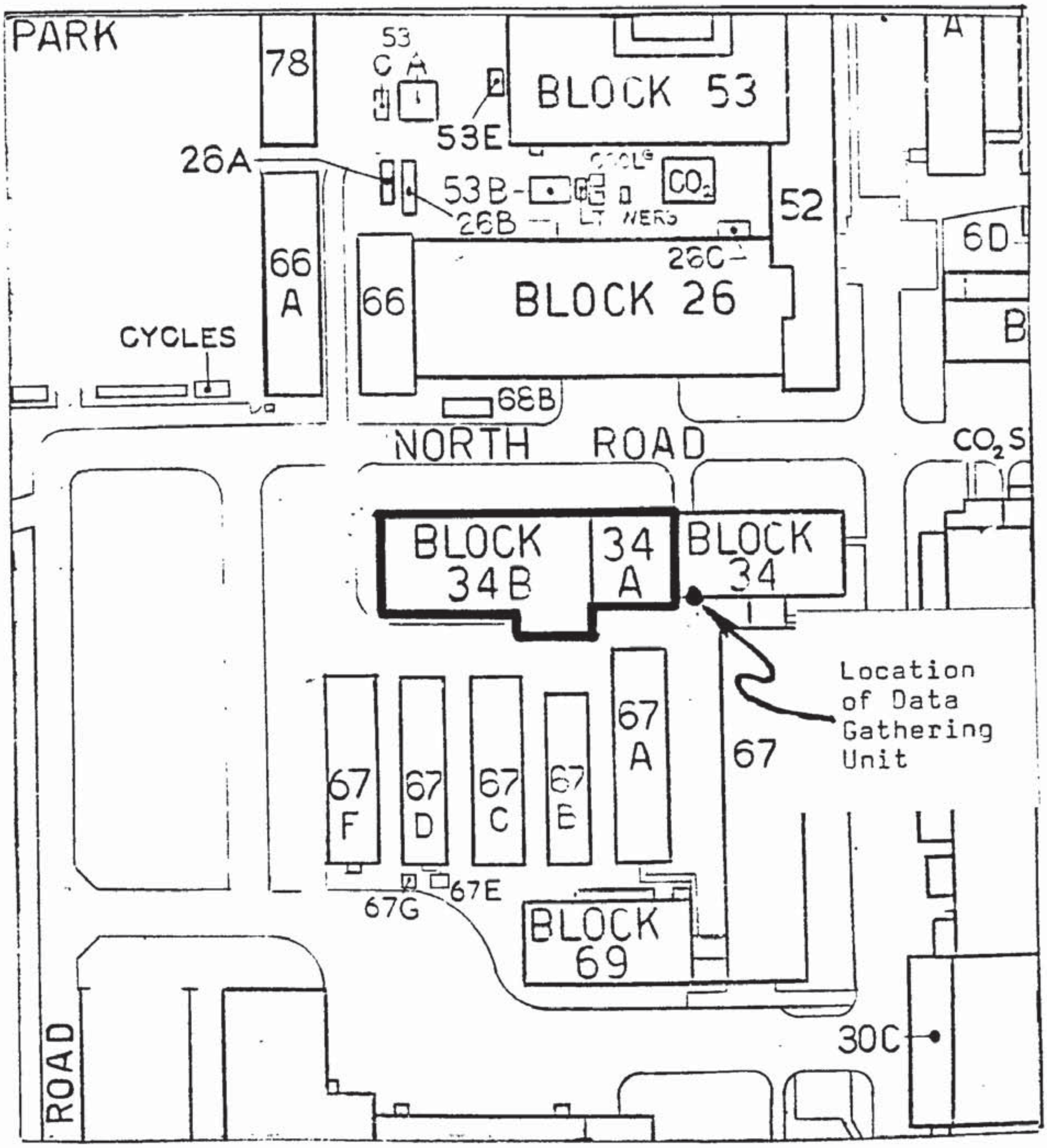
HEATING AREA : 06

Data gathering unit input	System input	Function
0	40	
1	41	
2	42	TD
3	43	FLOW
4		
5		
6		
7		



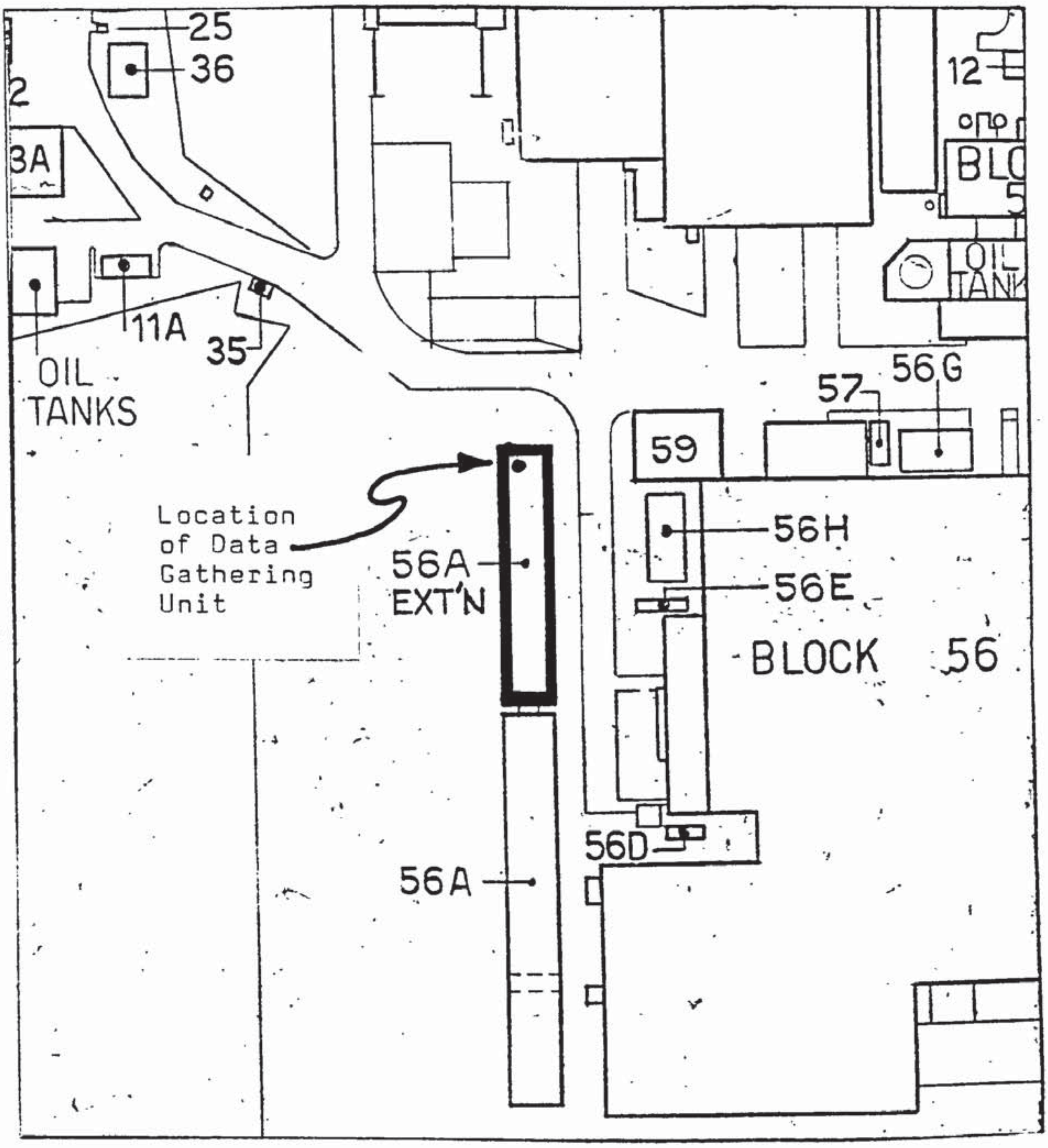
HEATING AREA : 07

Data gathering unit input	System input	Function
0	48	
1	49	
2	50	To
3	51	FLOW
4		
5		
6		
7		



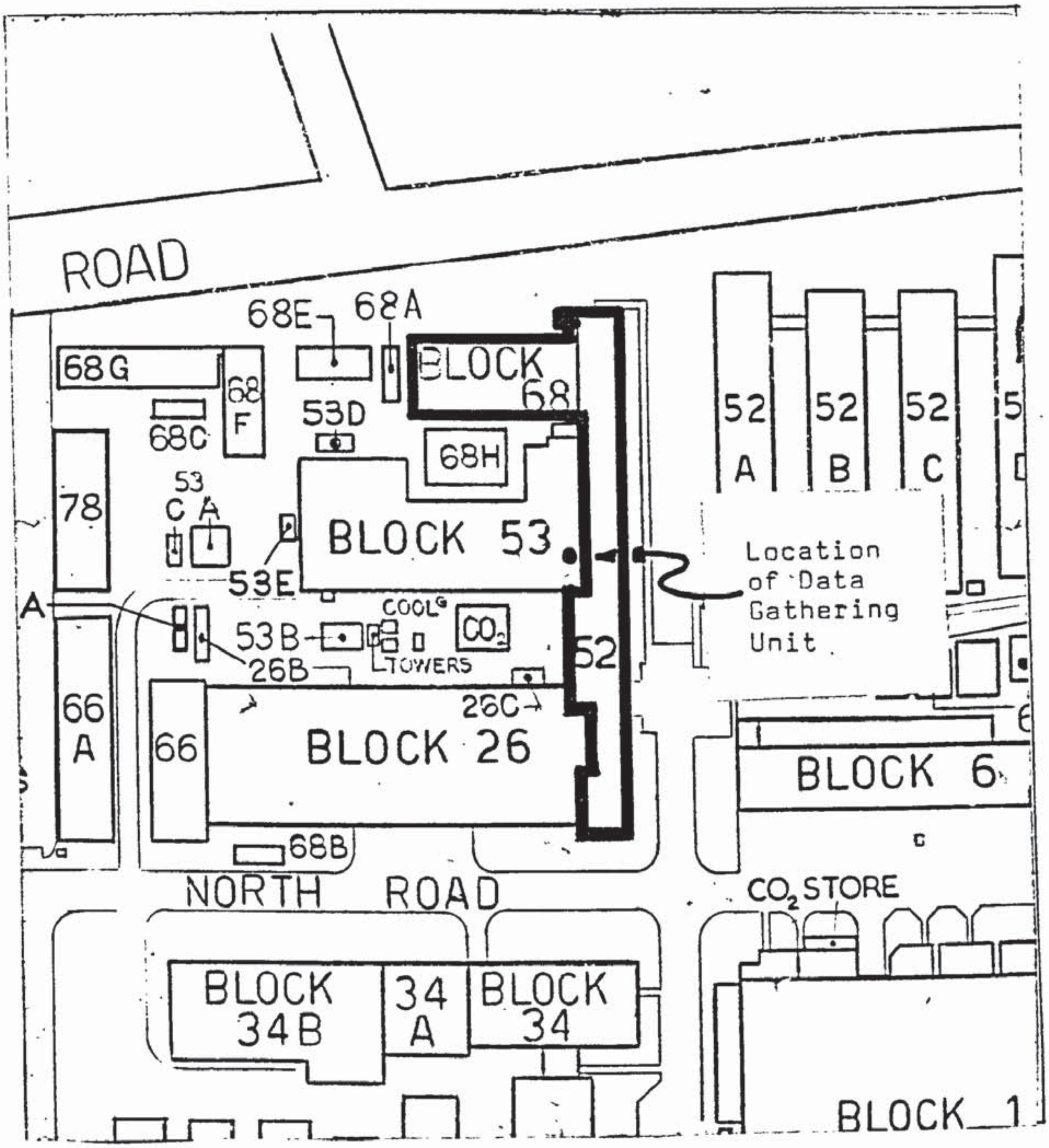
HEATING AREA : 08

Data gathering unit input	System input	Function
0	56	
1	57	
2	58	TD
3	59	FLOW
4	60	
5	61	
6	62	
7	63	



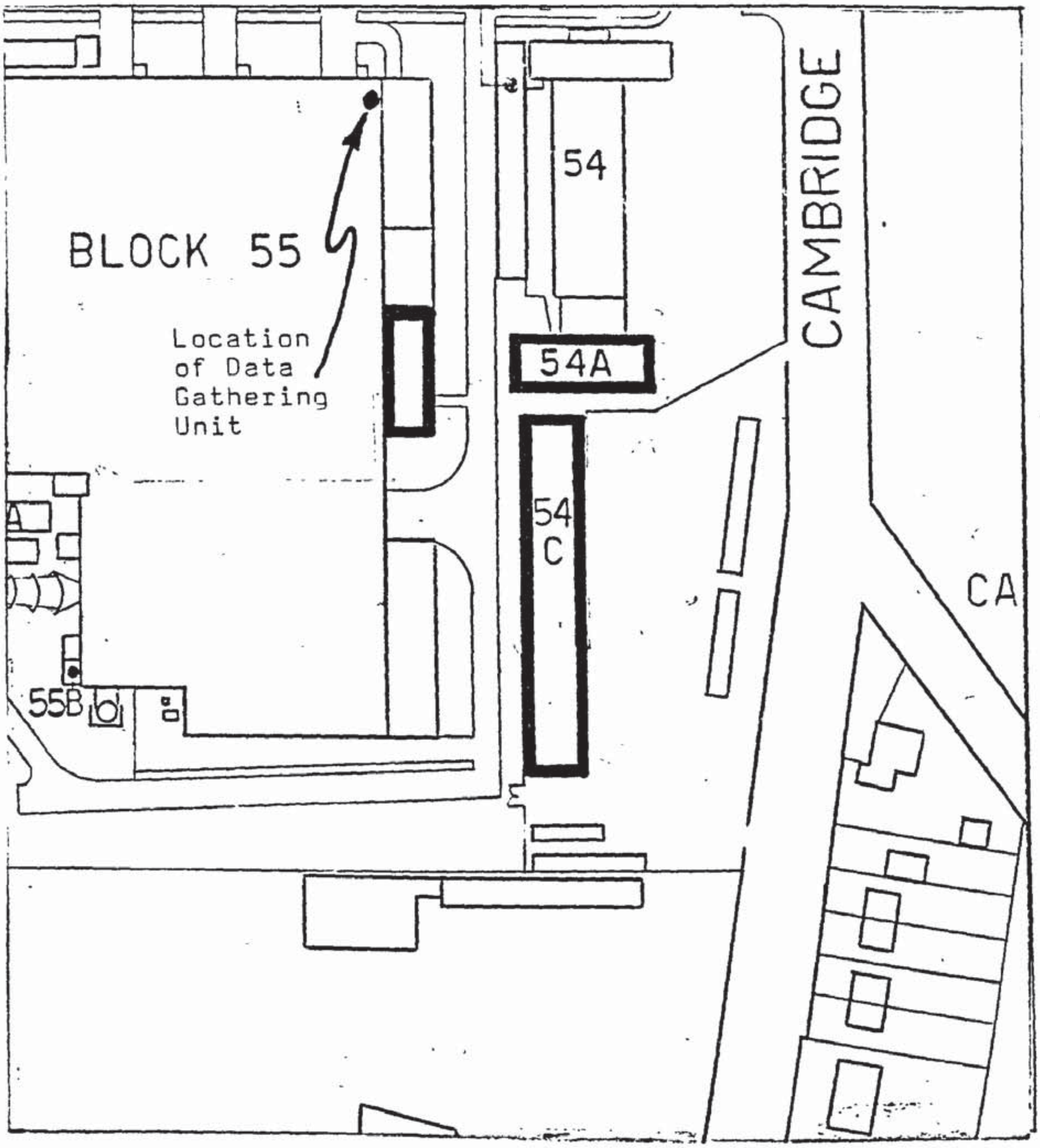
HEATING AREA : 09

Data gathering unit input	System input	Function
0	64	
1	65	
2	66	To
3	67	FLOW
4		
5		
6		
7		



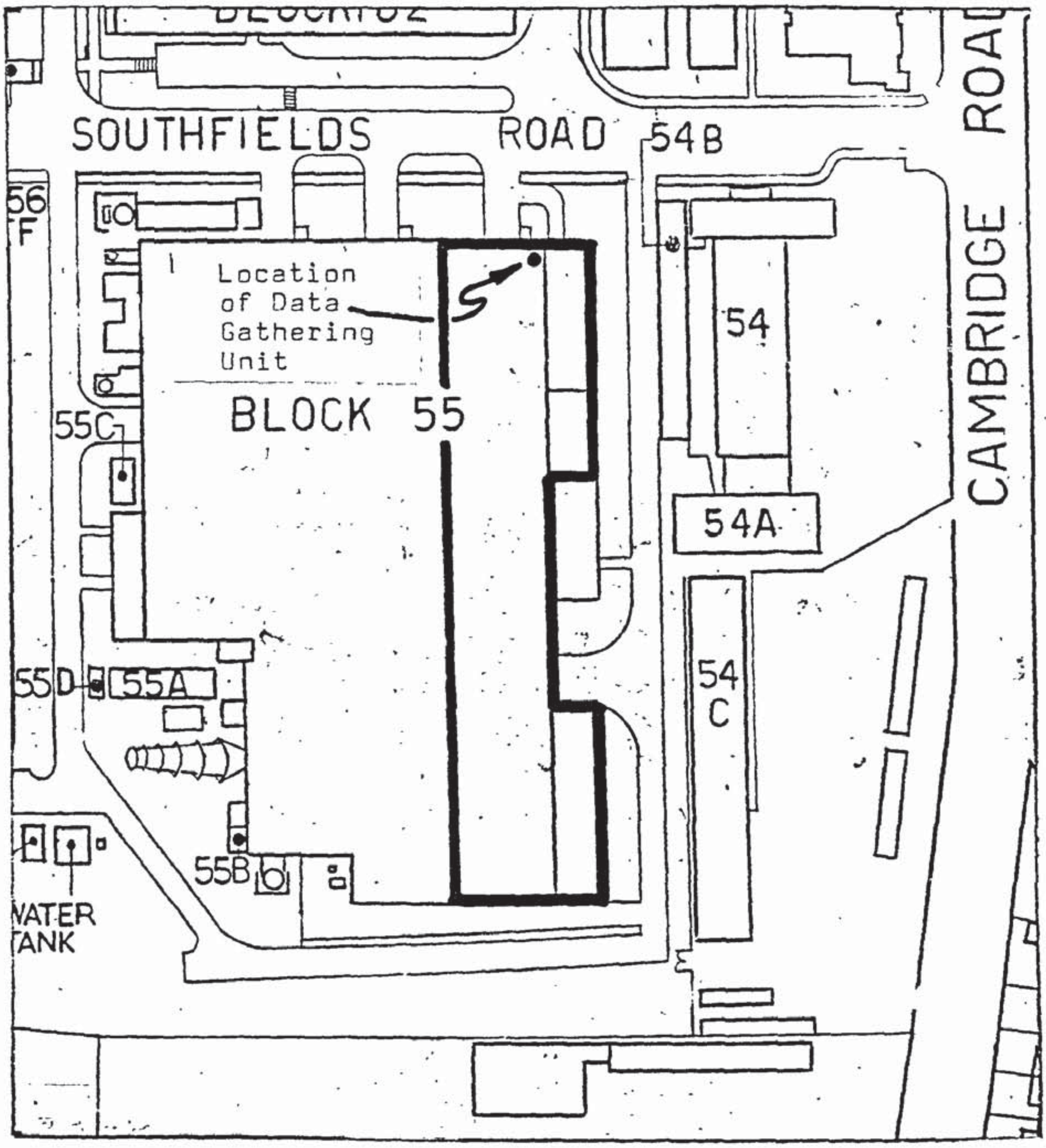
HEATING AREA : 10

Data gathering unit input	System input	Function
0	72	
1	73	
2	74	T_D
3	75	FLOW
4		
5		
6		
7		



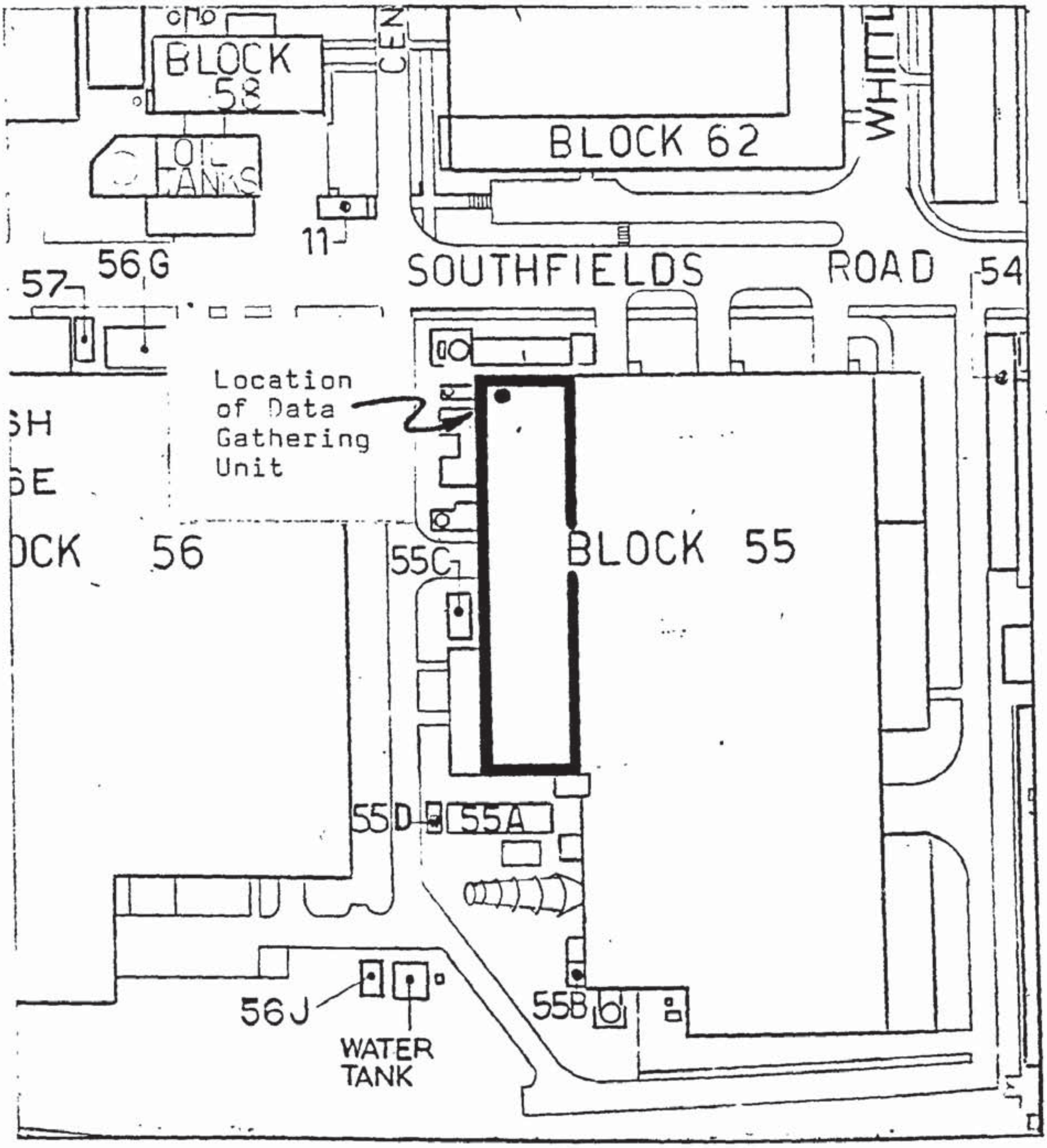
HEATING AREA : 11

Data gathering unit input	System input	Function
0	80	
1	81	
2	82	T_D
3	83	FLOW
4	84	
5	85	
6	86	
7	87	



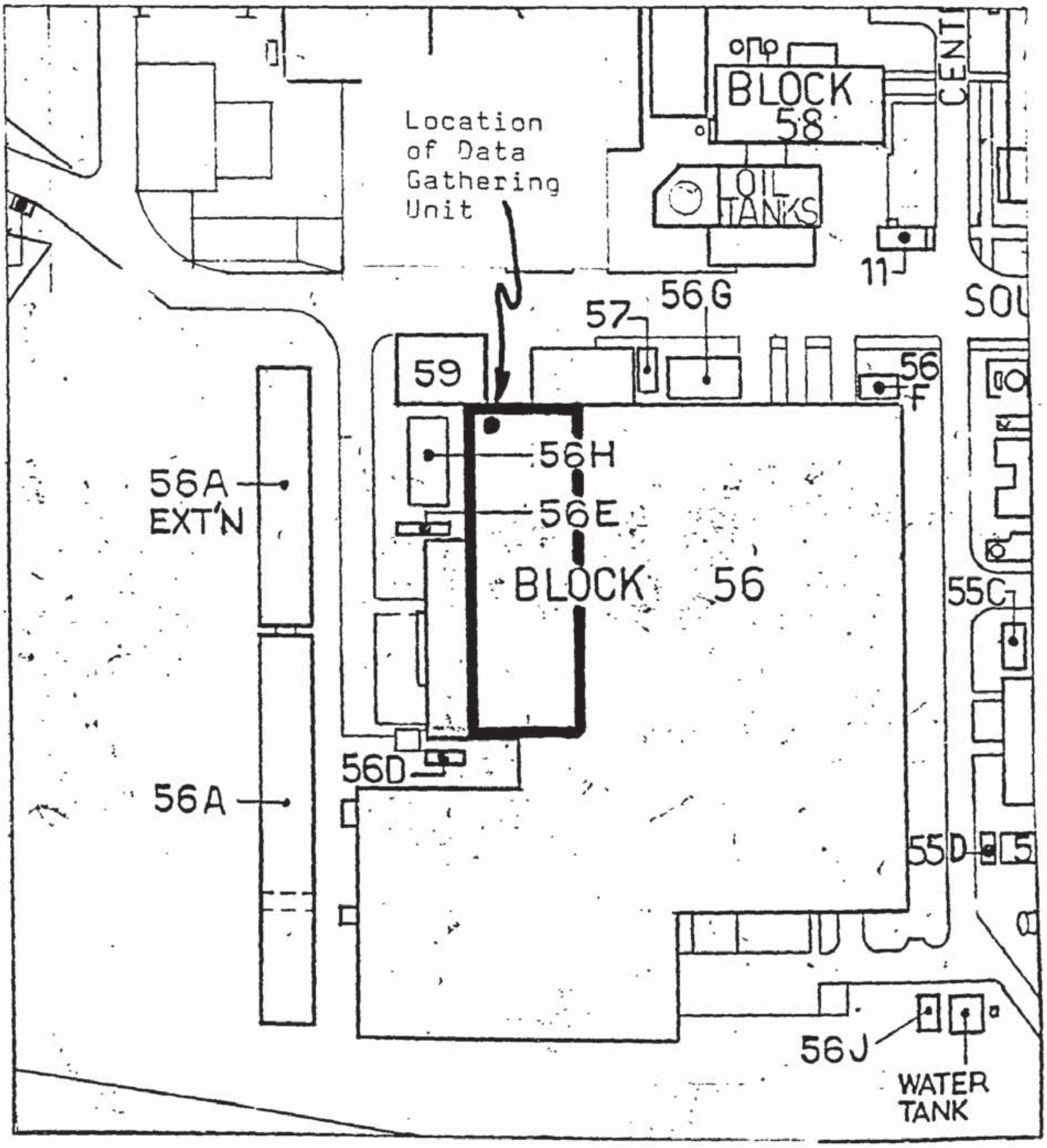
HEATING AREA : 12

Data gathering unit input	System input	Function
0	80	T_D
1	81	FLOW (INCLUDES HEATING AREA 11)
2	82	
3	83	
4	84	
5	85	
6	86	
7	87	



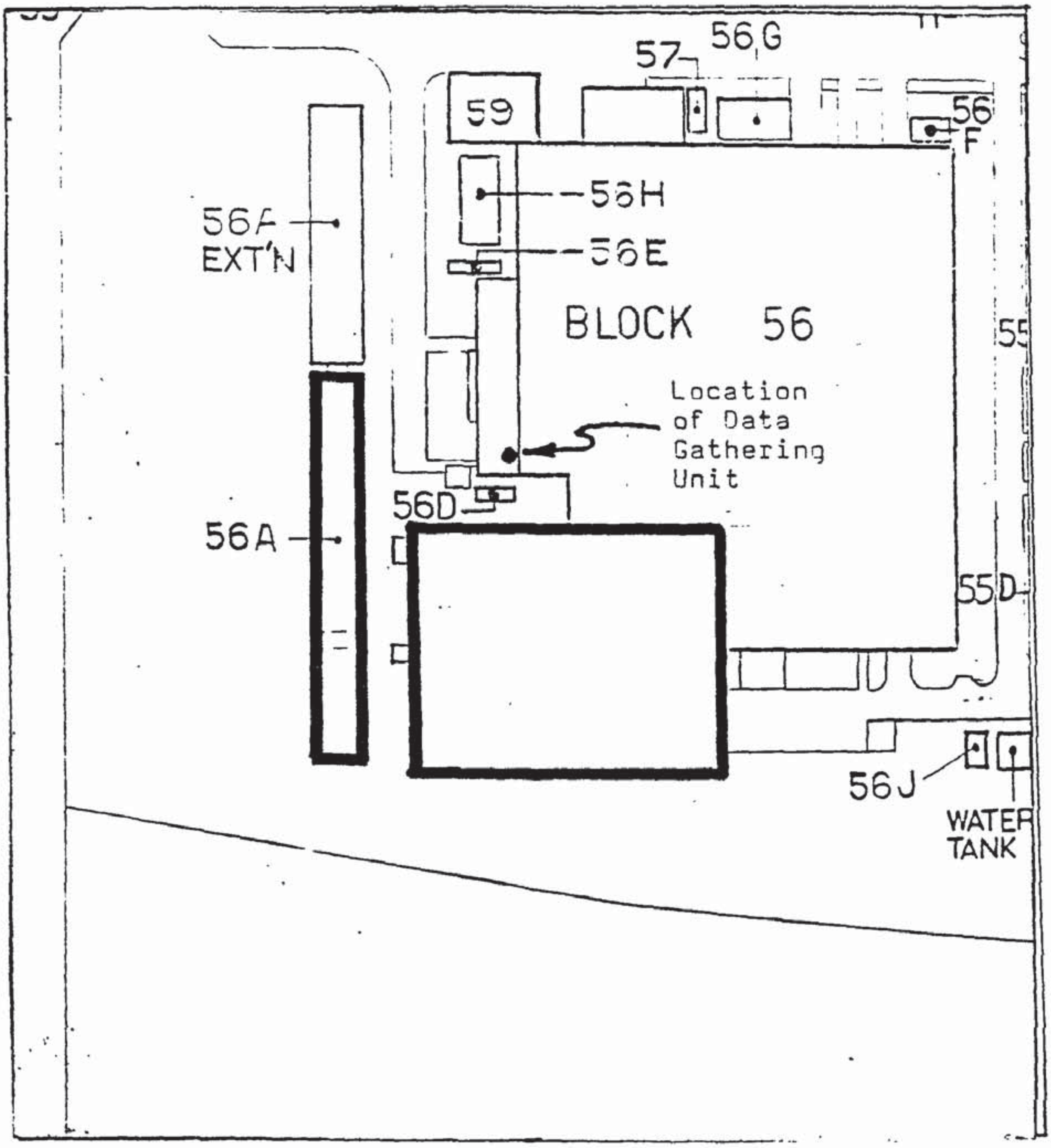
HEATING AREA : 13

Data gathering unit input	System input	Function
0	88	
1	89	To
2	90	
3	91	FLOW
4		
5		
5		
7		



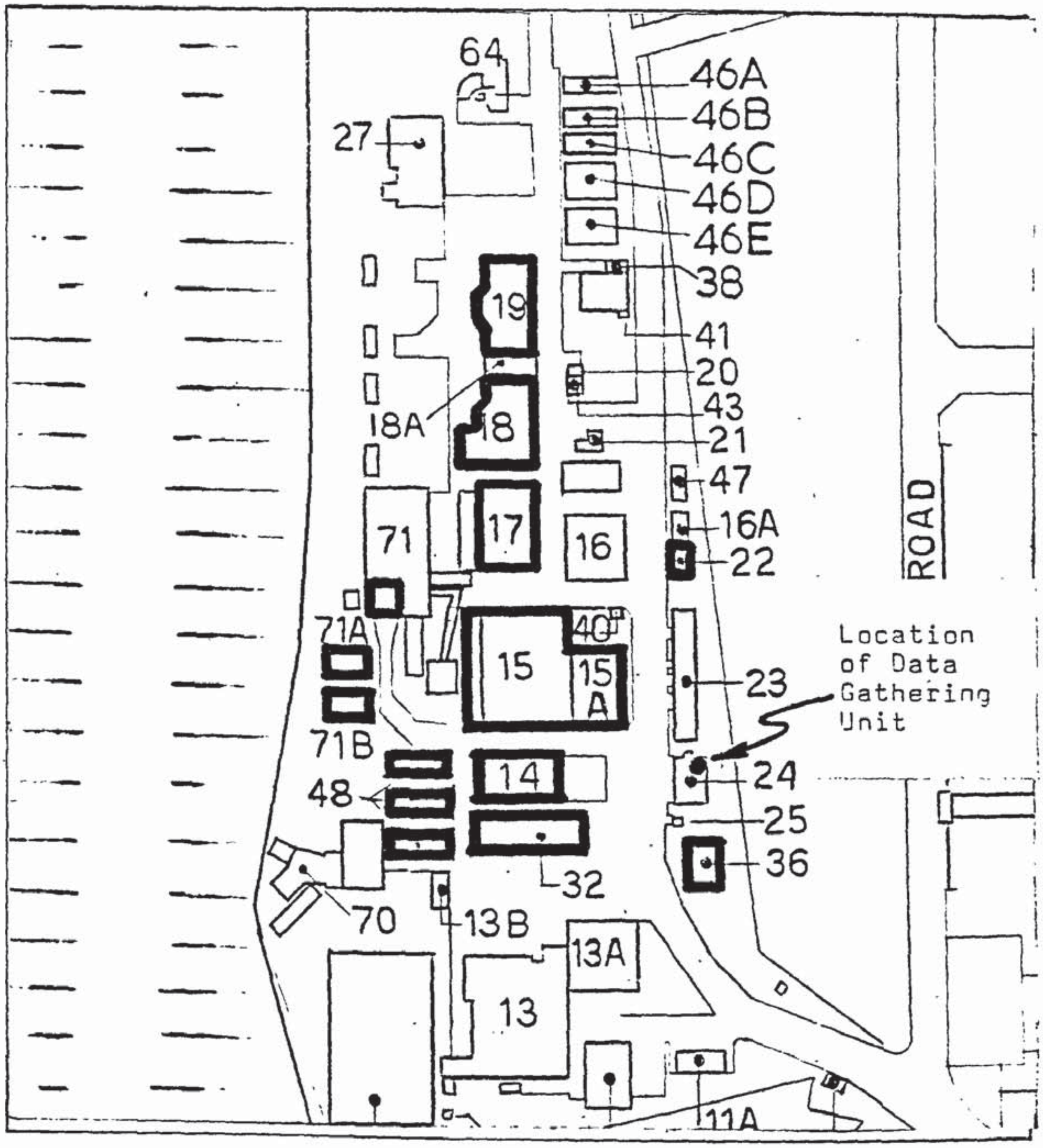
HEATING AREA : 14

Data gathering unit input	System input	Function
0	96	
1	97	
2	98	T_D
3	99	FLOW
4		
5		
6		
7		



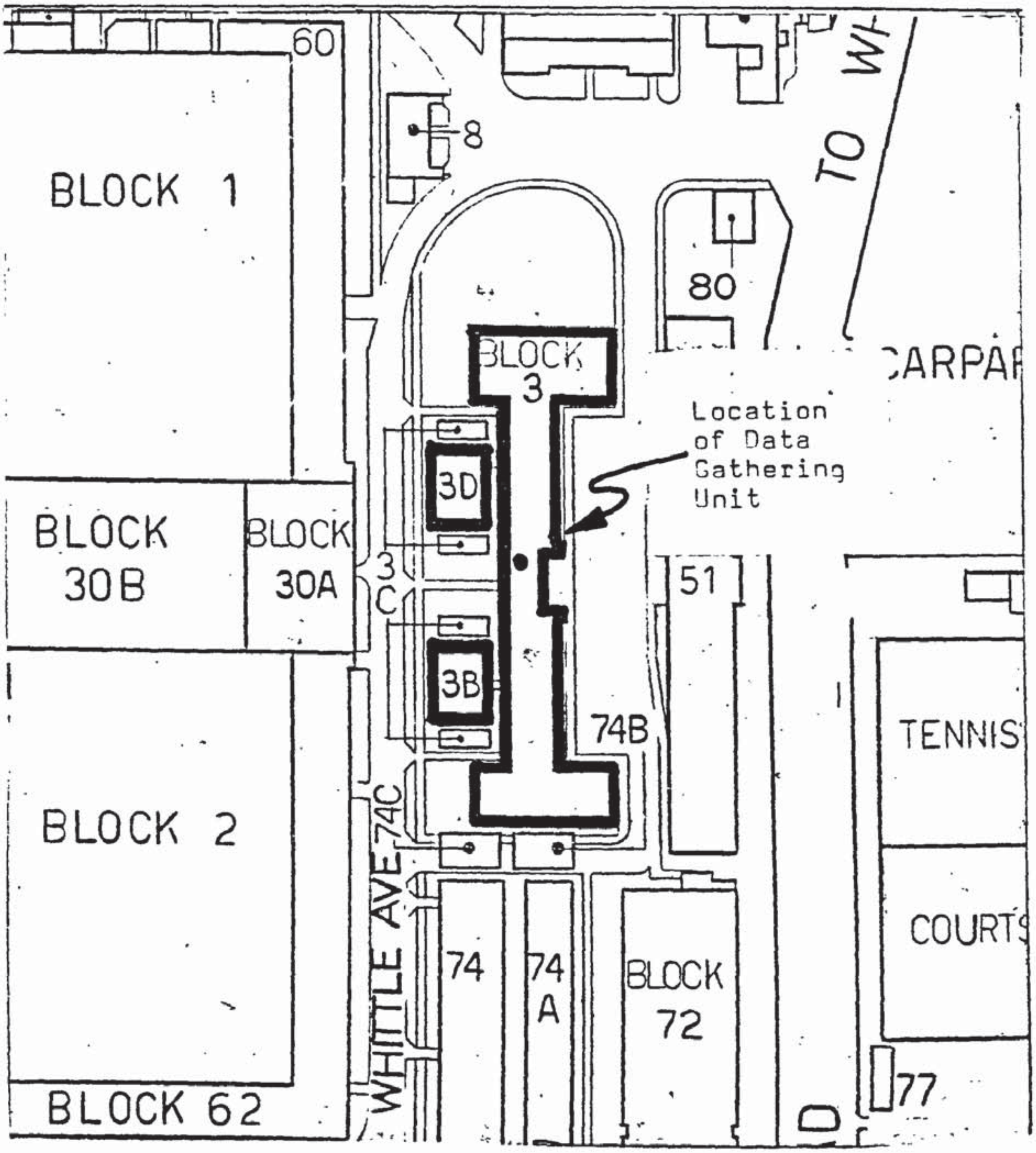
HEATING AREA : 15

Data gathering unit input	System input	Function
0	104	
1	105	
2	106	T_D
3	107	FLOW
4		
5		
6		
7		



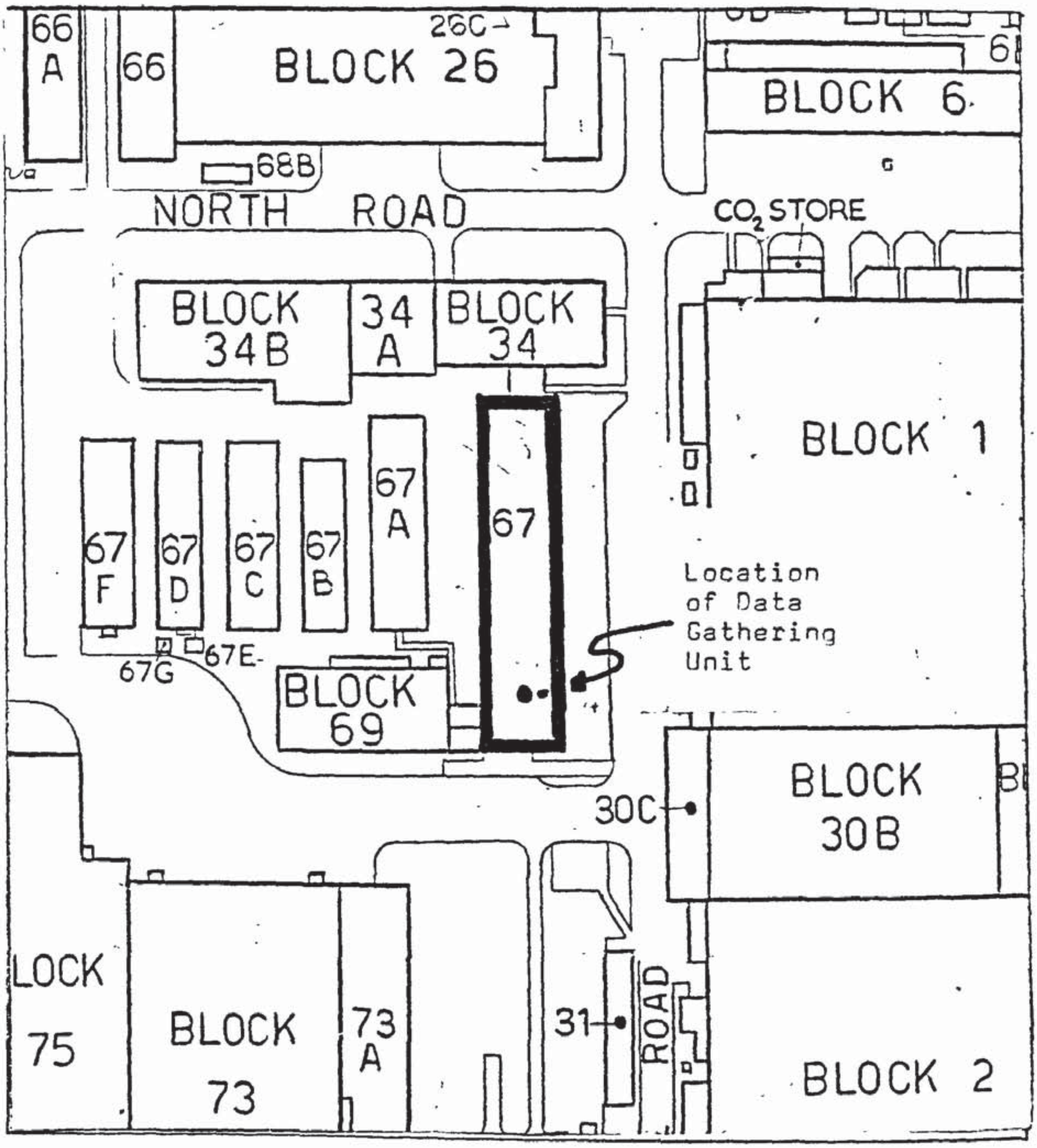
HEATING AREA : 16

Data gathering unit input	System input	Function
0	112	
1	113	
2	114	To
3	115	FLOW
4		
5		
6		
7		



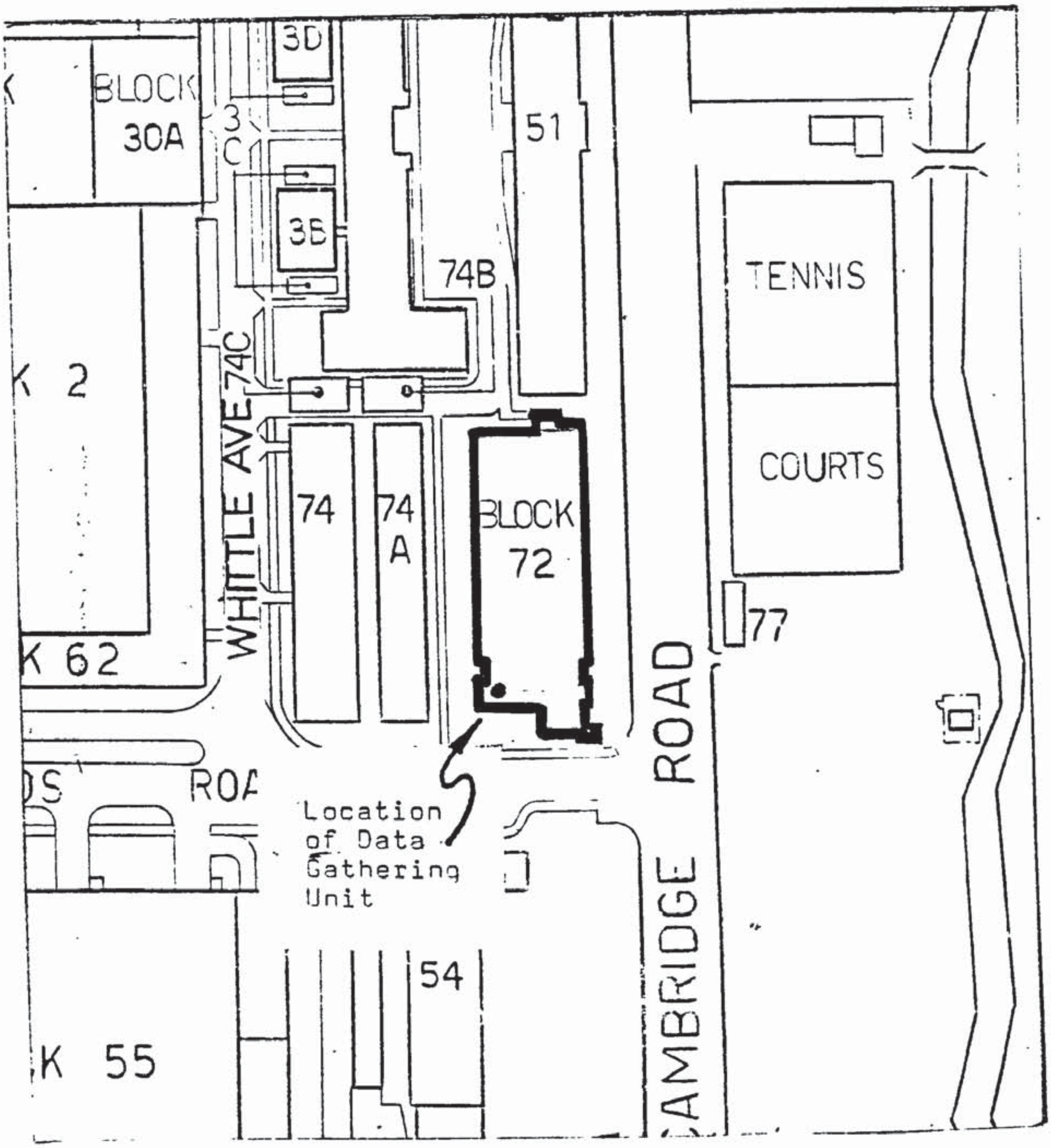
HEATING AREA : 17

Data gathering unit input	System input	Function
0	8	
1	9	
2	10	TO
3	11	FLOW
4		
5		
6		
7		



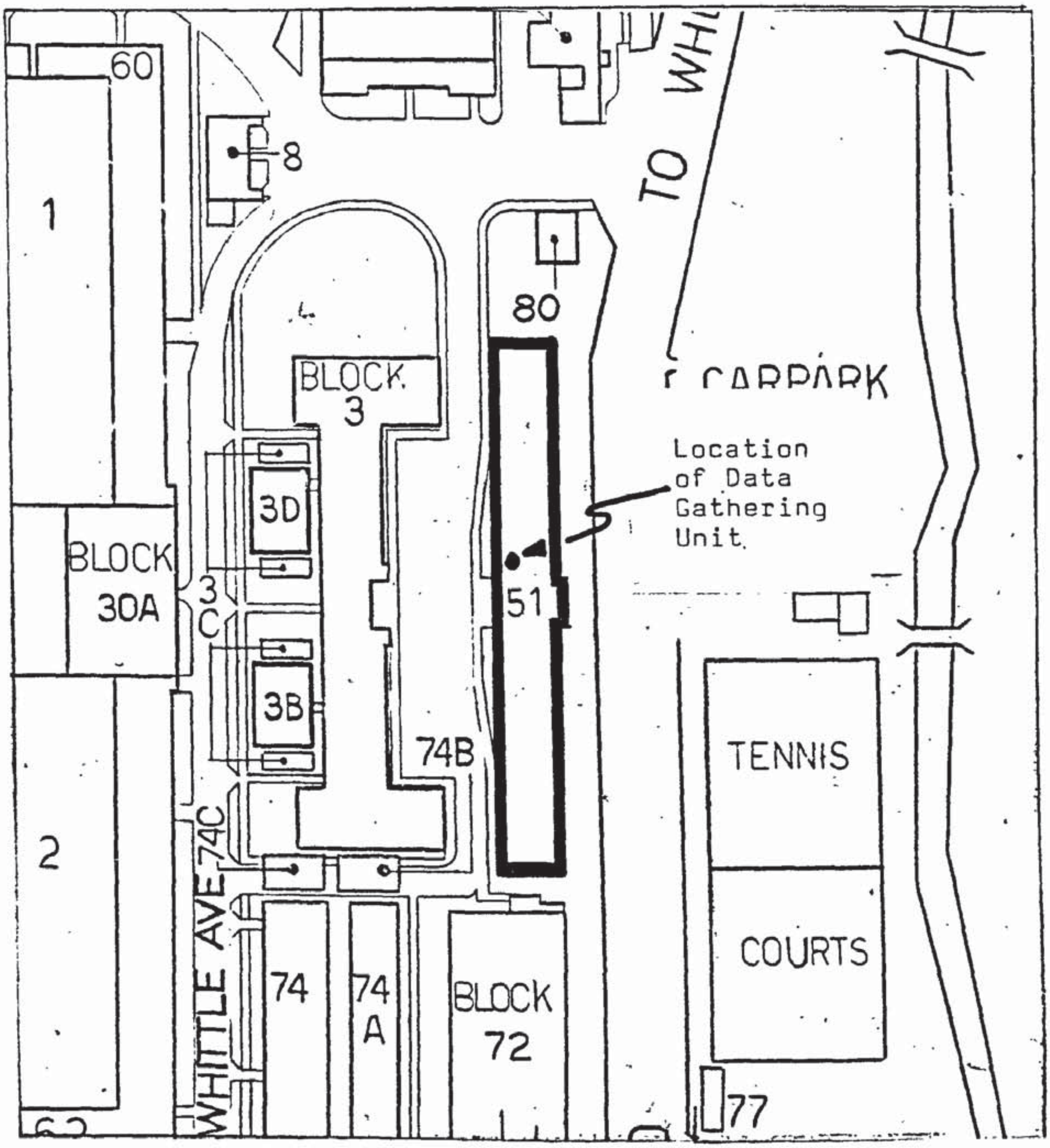
HEATING AREA : 18

Data gathering unit input	System input	Function
0	120	
1	121	
2	122	To
3	123	FLOW
4		
5		
6		
7		



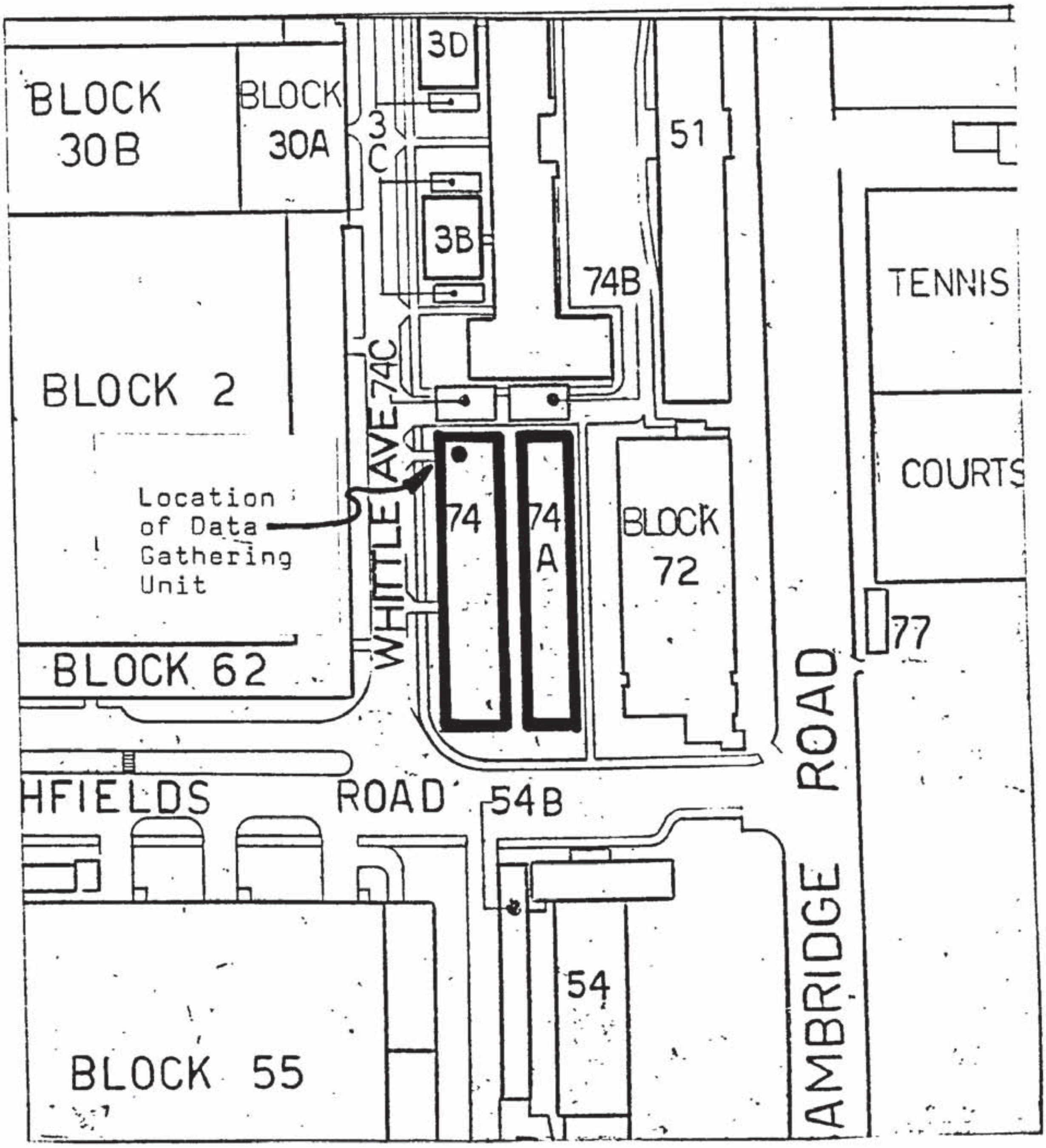
HEATING AREA : 19

Data gathering unit input	System input	Function
0	128	
1	129	
2	130	T_D
3	131	FLOW
4		
5		
6		
7		



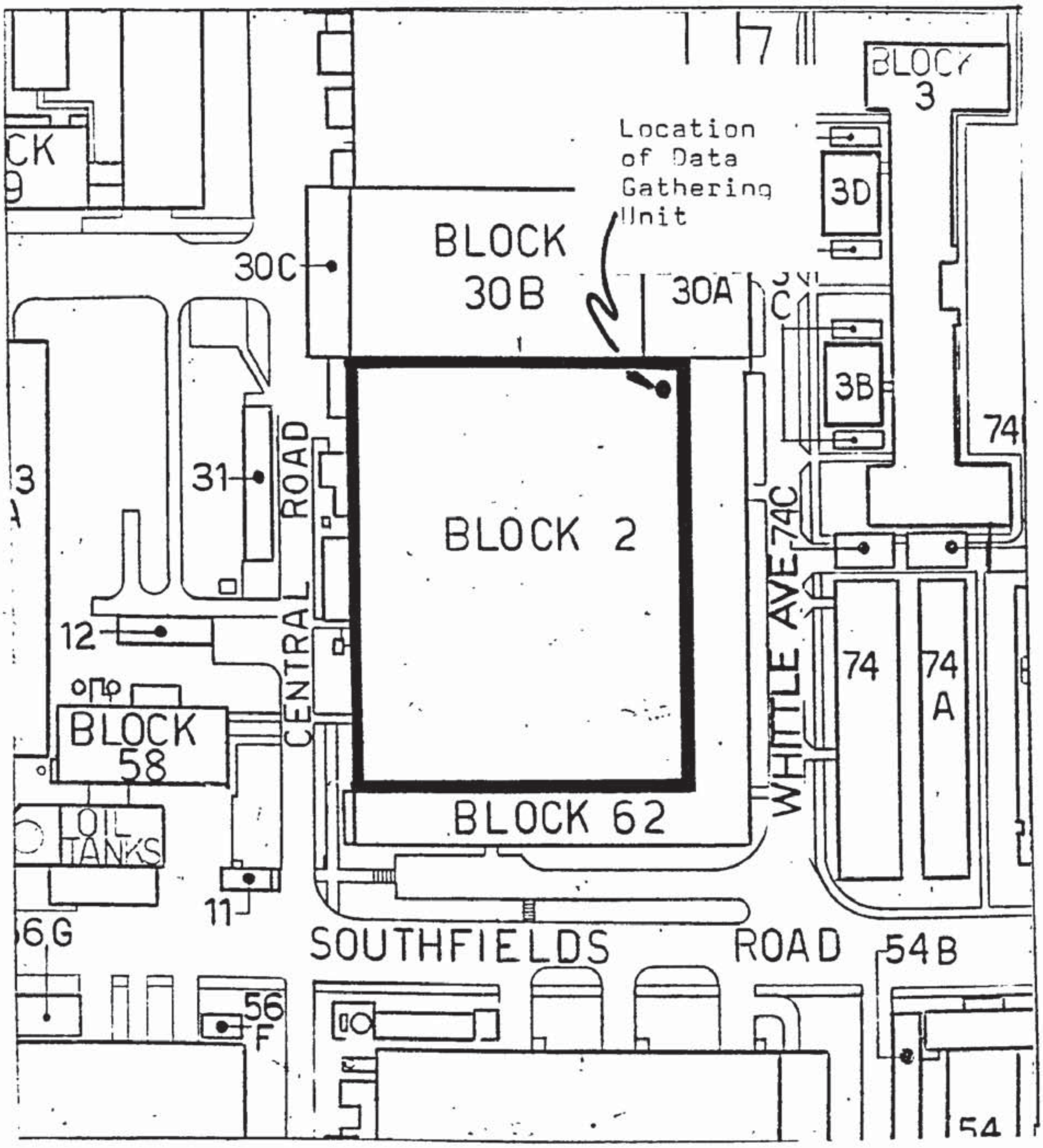
HEATING AREA : 20

Data gathering unit input	System input	Function
0	12	
1	13	
2	14	To
3	15	FLOW
4		
5		
6		
7		



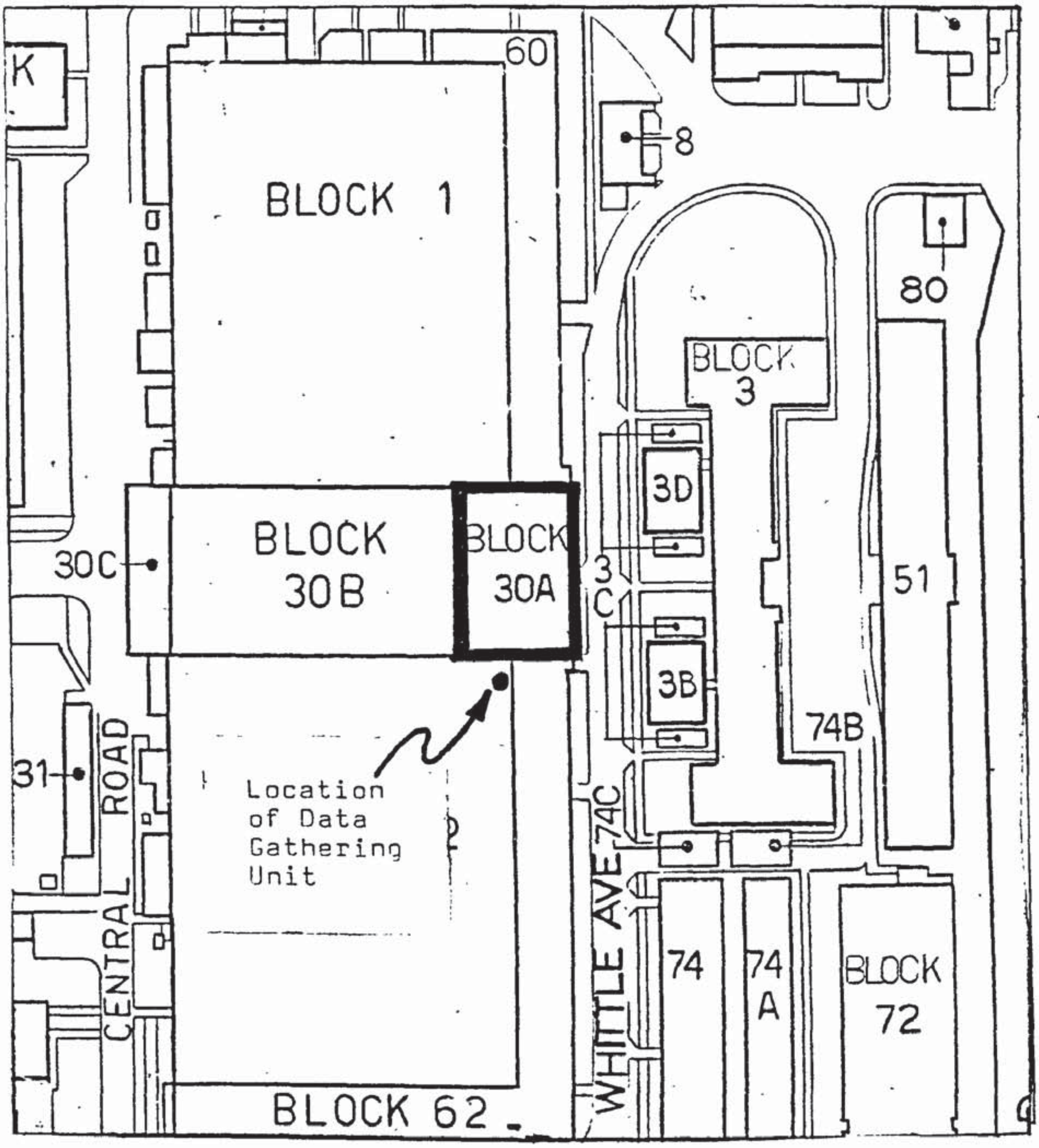
HEATING AREA : 21

Data gathering unit input	System input	Function
0	136	
1	137	
2	138	T_D
3	139	FLOW
4		
5		
6		
7		



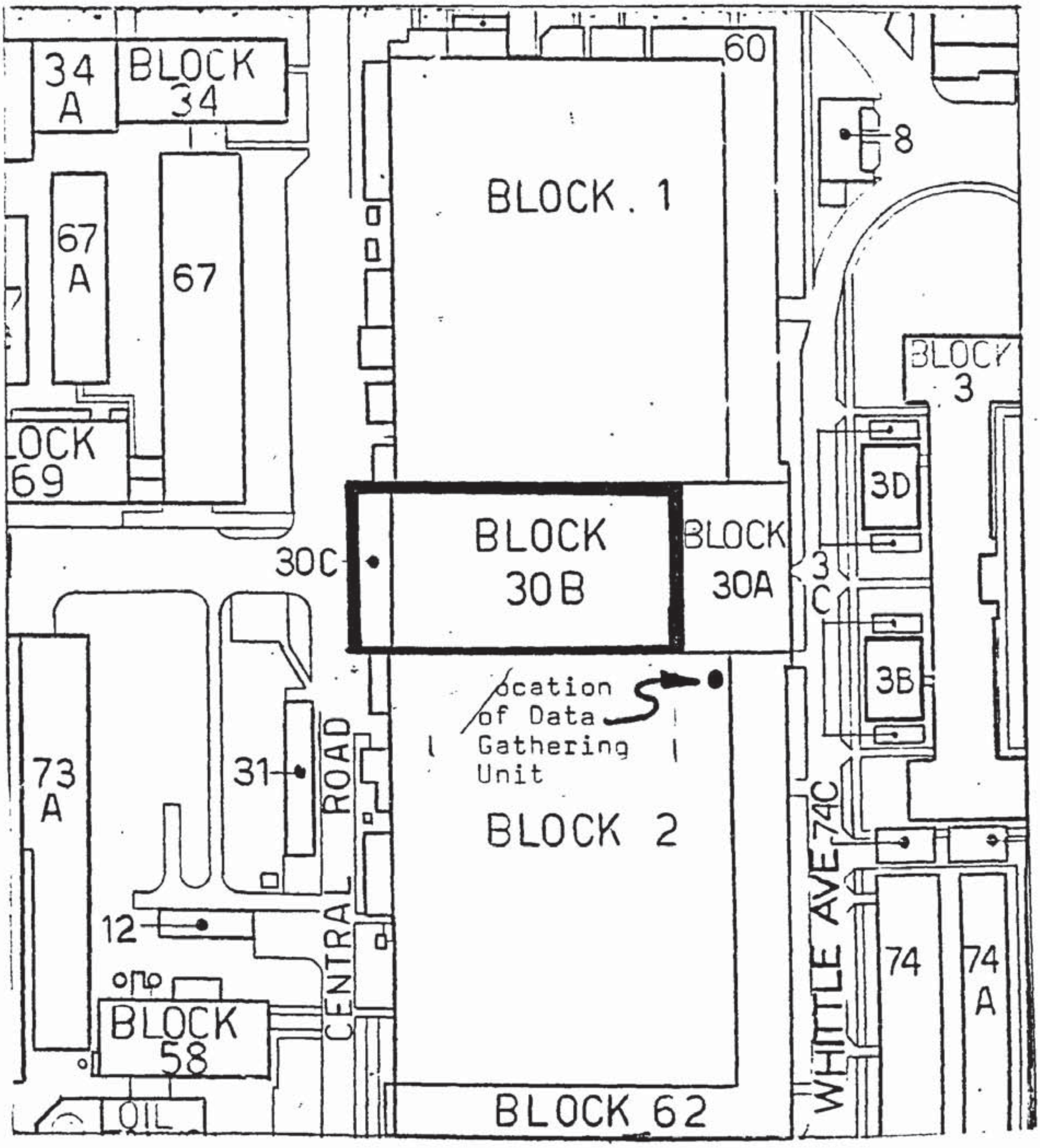
HEATING AREA : 22

Data gathering unit input	System input	Function
0	144	To
1	145	FLOW
2	146	
3	147	
4	148	
5	149	
6	150	
7	151	



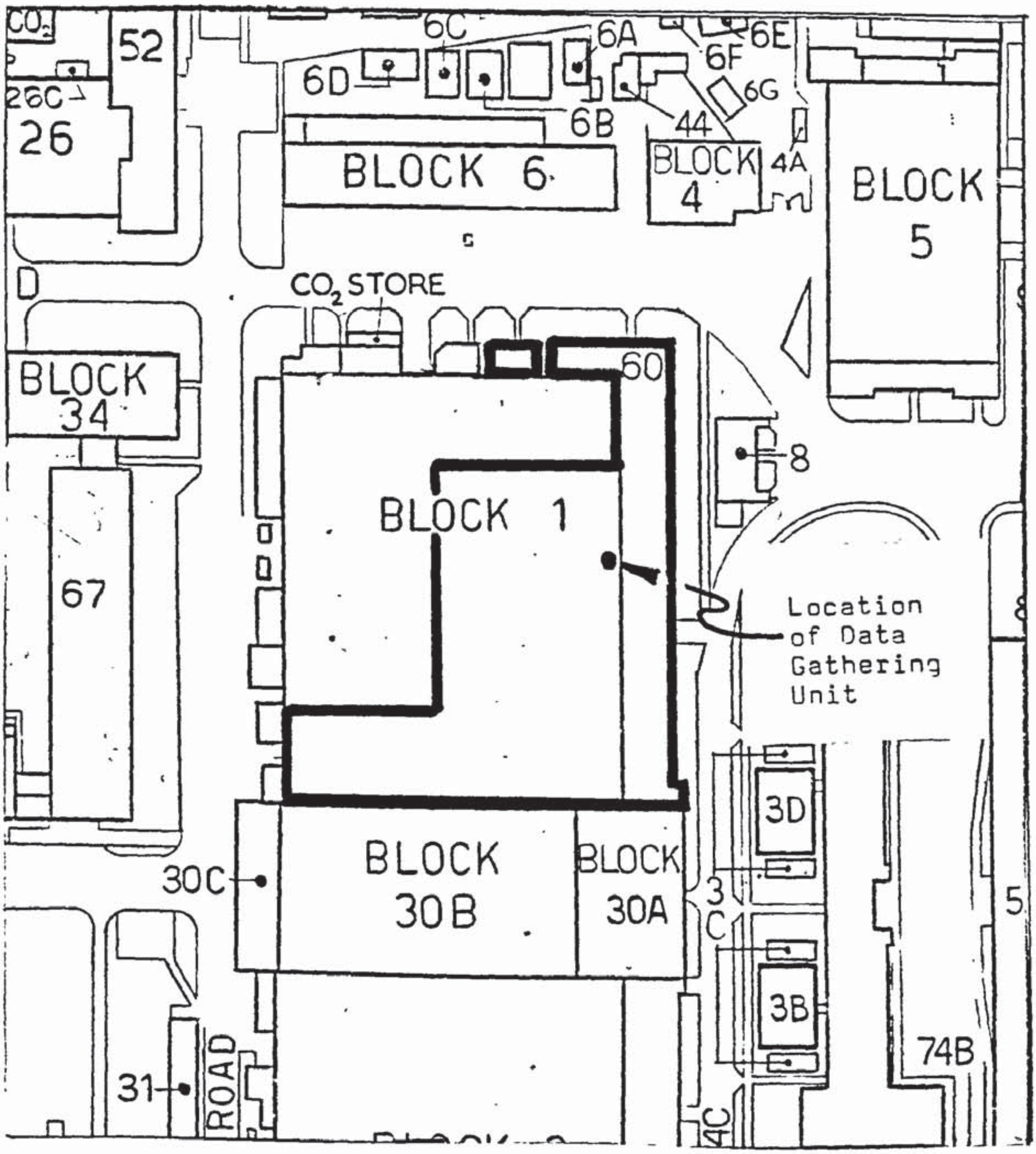
HEATING AREA : 23

Data gathering unit input	System input	Function
0	144	
1	145	
2	146	To
3	147	FLOW
4	148	
5	149	
6	150	
7	151	



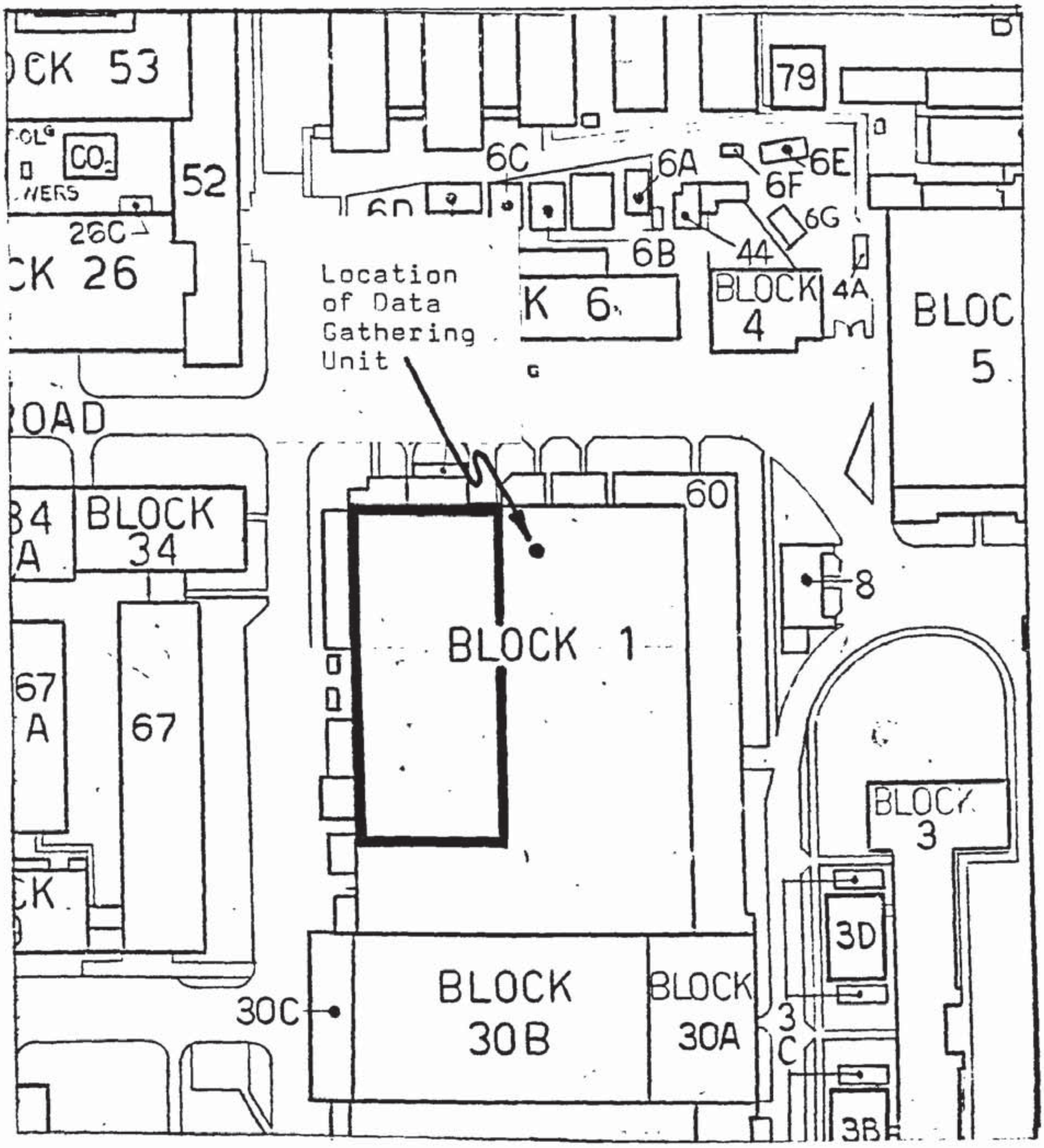
HEATING AREA : 24

Data gathering unit input	System input	Function
0	144	
1	145	
2	146	
3	147	
4	148	To
5	149	FLOW
6	150	
7	151	



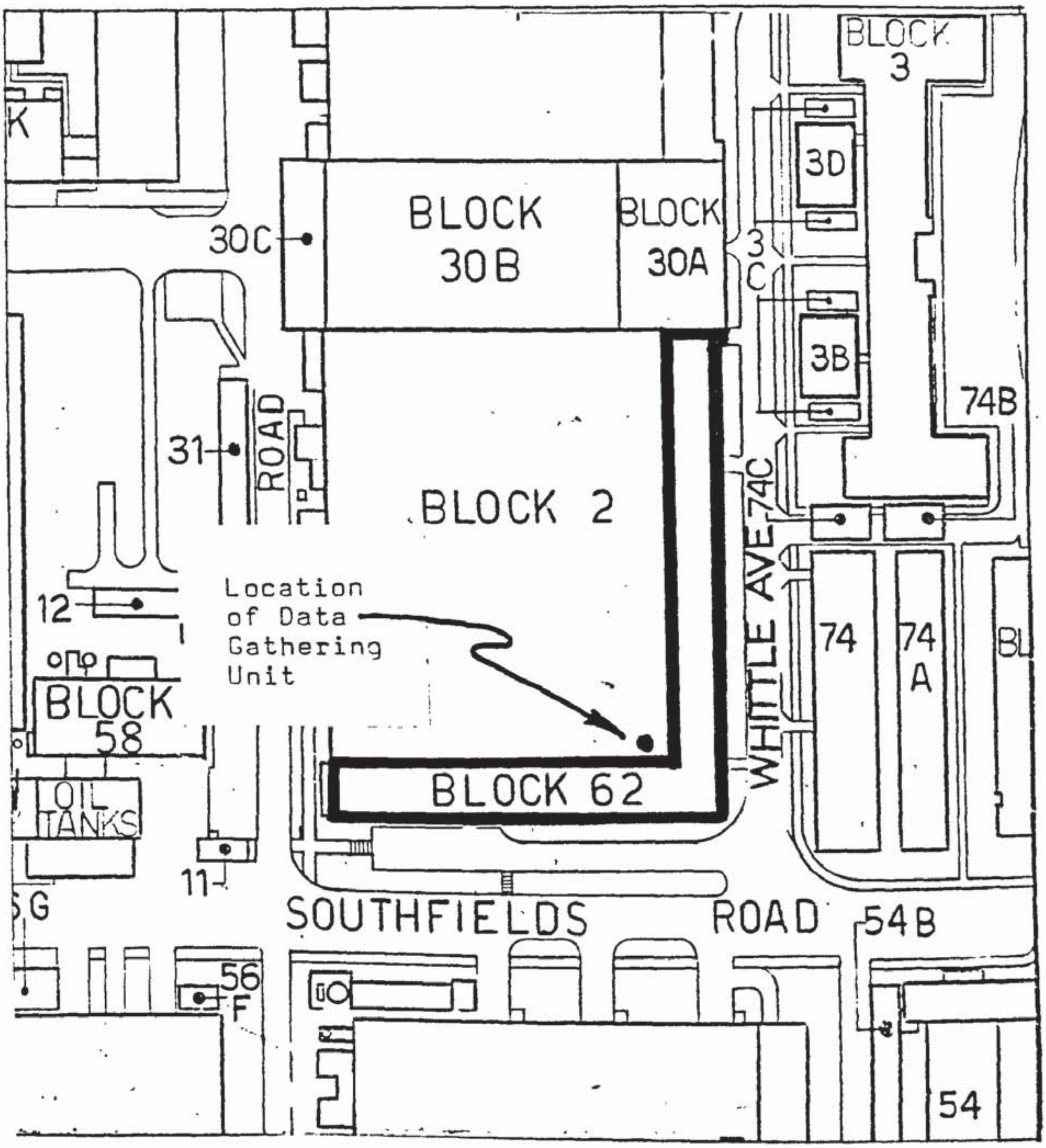
HEATING AREA : 25

Data gathering unit input	System input	Function
0	152	
1	153	
2	154	To
3	155	FLOW
4		
5		
6		
7		



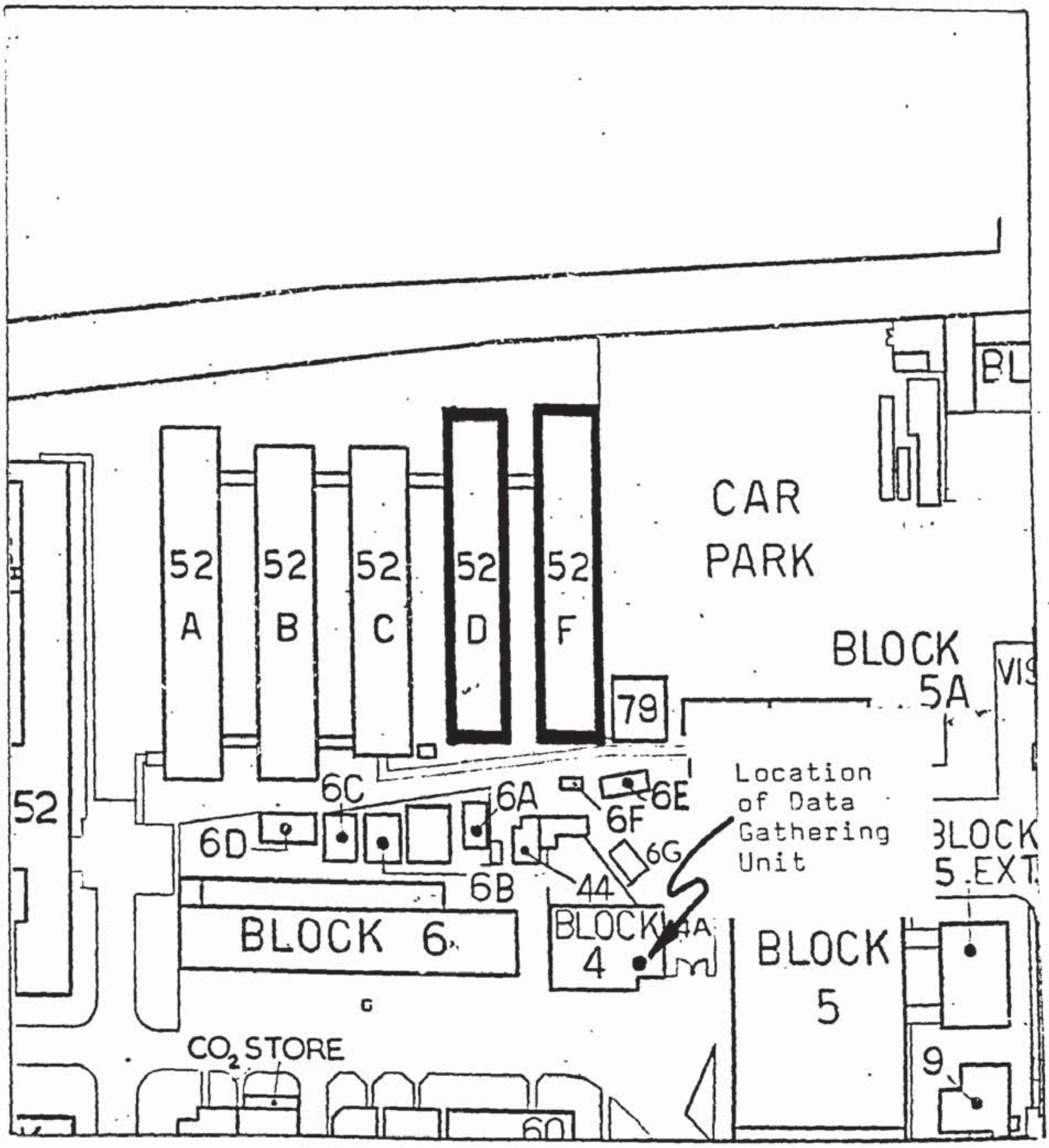
HEATING AREA : 26

Data gathering unit input	System input	Function
0	160	
1	161	
2	162	To
3	163	FLOW
4		
5		
6		
7		



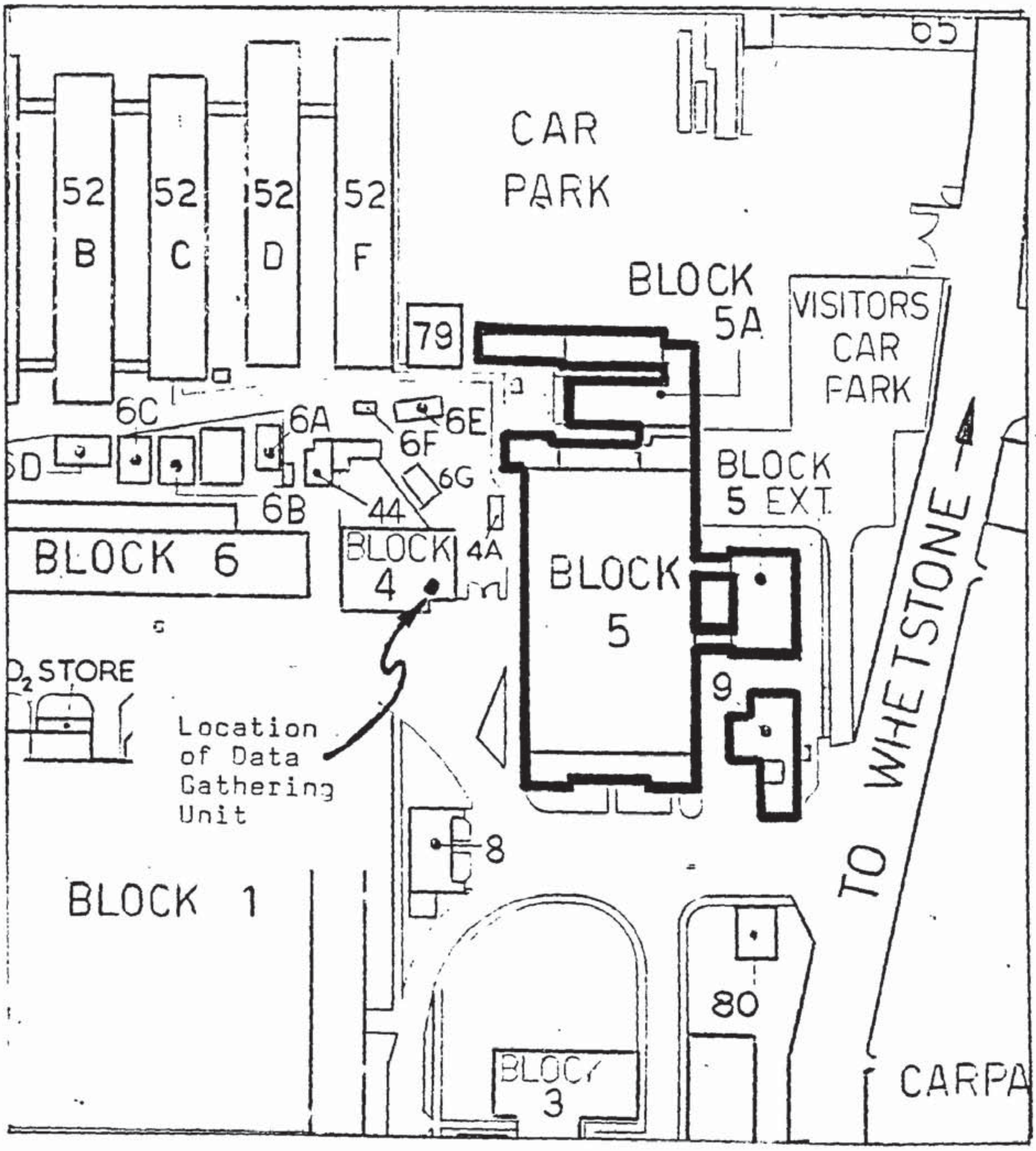
HEATING AREA : 27

Data gathering unit input	System input	Function
0	168	
1	169	
2	170	To
3	171	FLOW
4		
5		
6		
7		



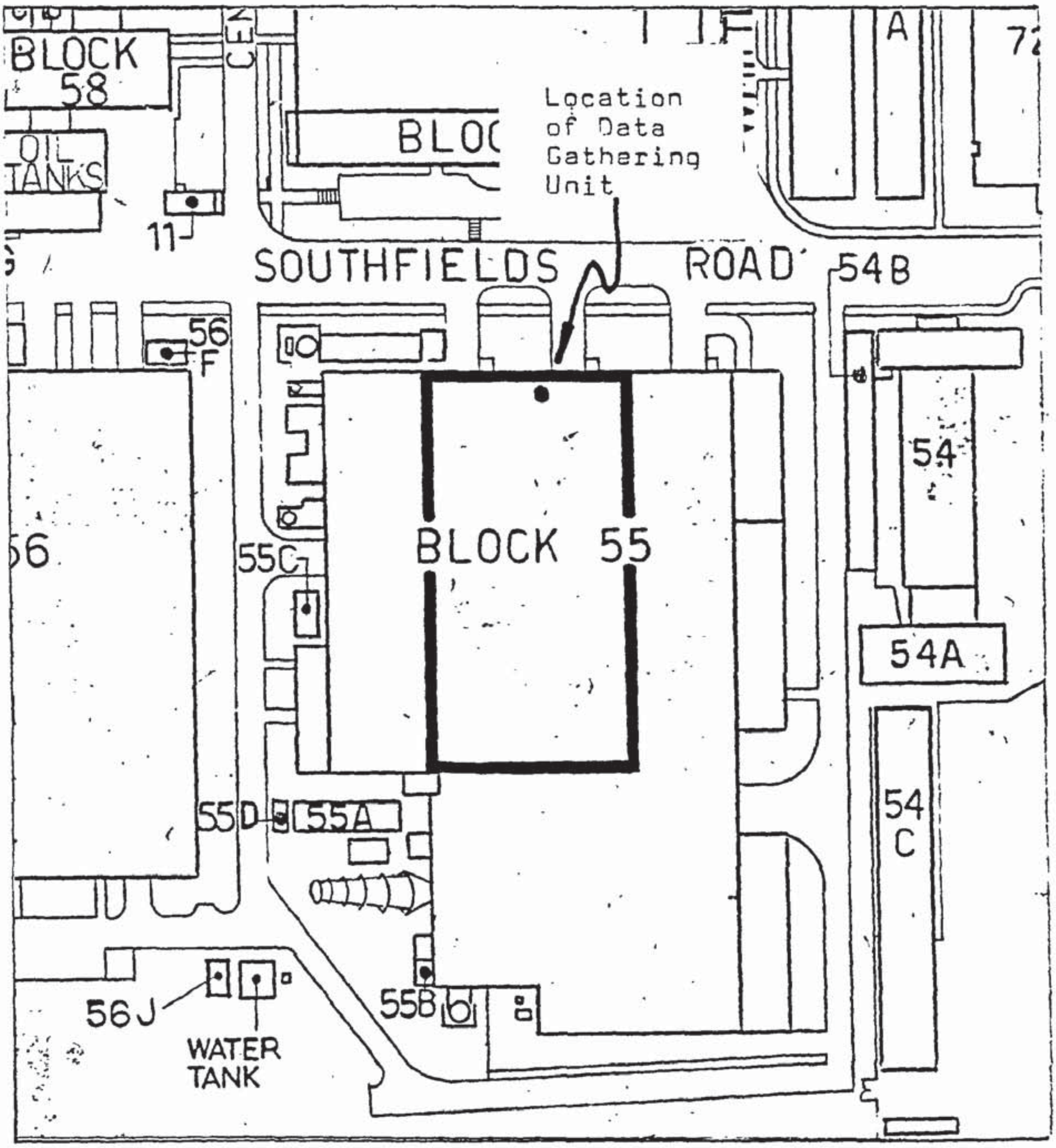
HEATING AREA : 28

Data gathering unit input	System input	Function
0	176	T_D
1	177	FLOW
2	178	
3	179	
4		
5		
6		
7		



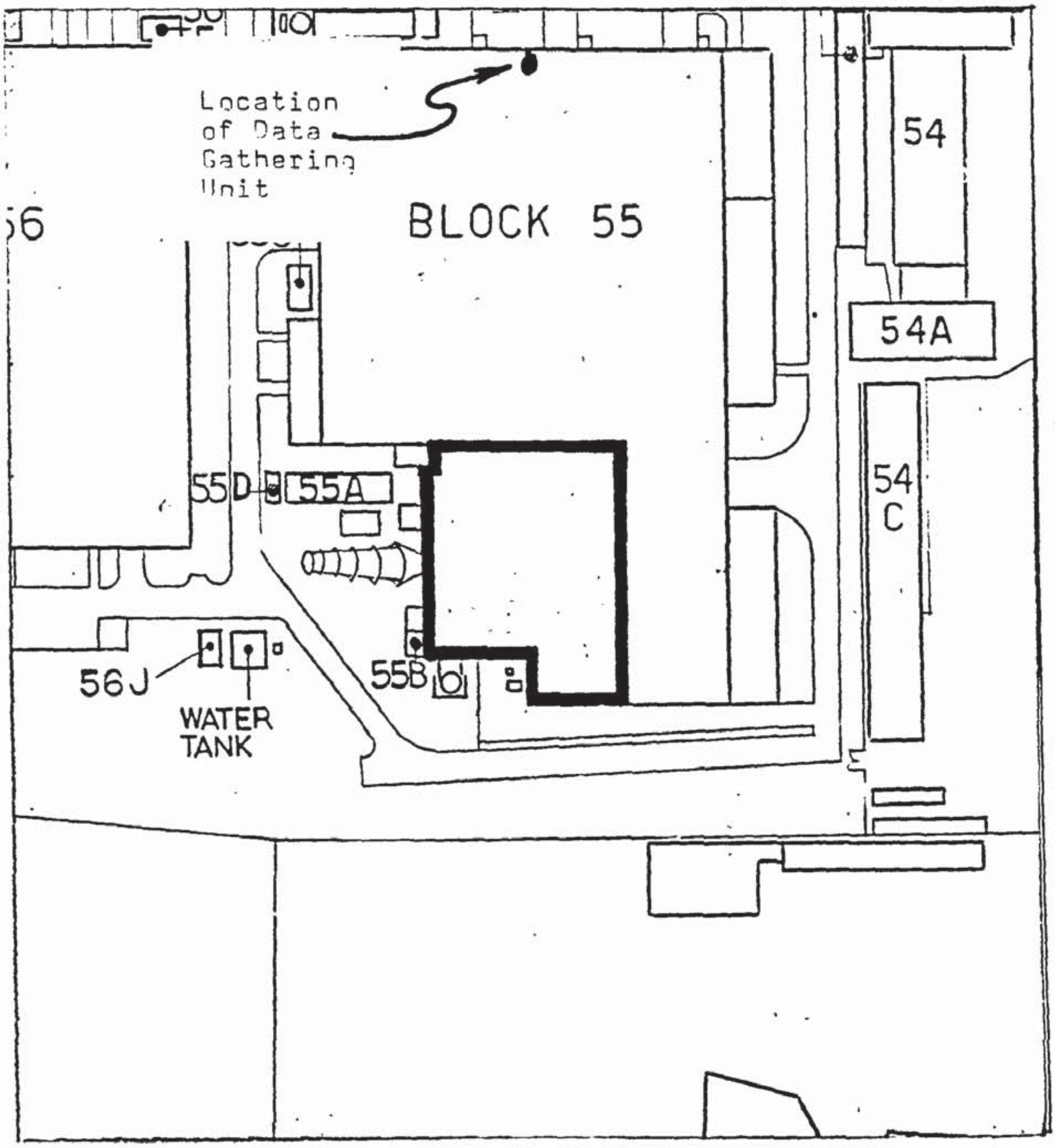
HEATING AREA : 29

Data gathering unit input	System input	Function
0	176	
1	177	
2	178	To
3	179	FLOW
4		
5		
6		
7		



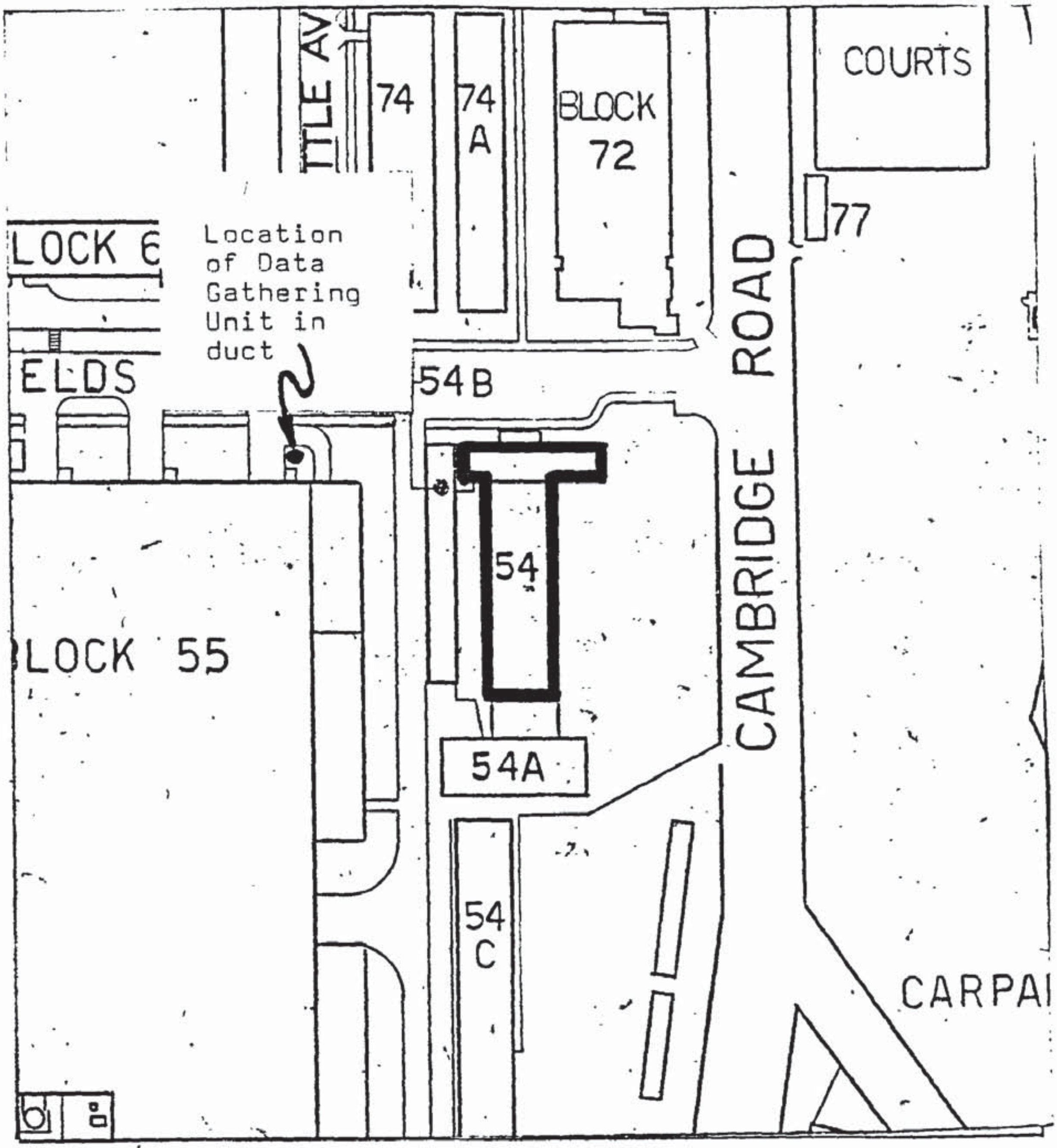
HEATING AREA : 30

Data gathering unit input	System input	Function
0	184	
1	185	
2	186	T_o
3	187	FLOW
4	188	
5	189	
6	190	
7	191	



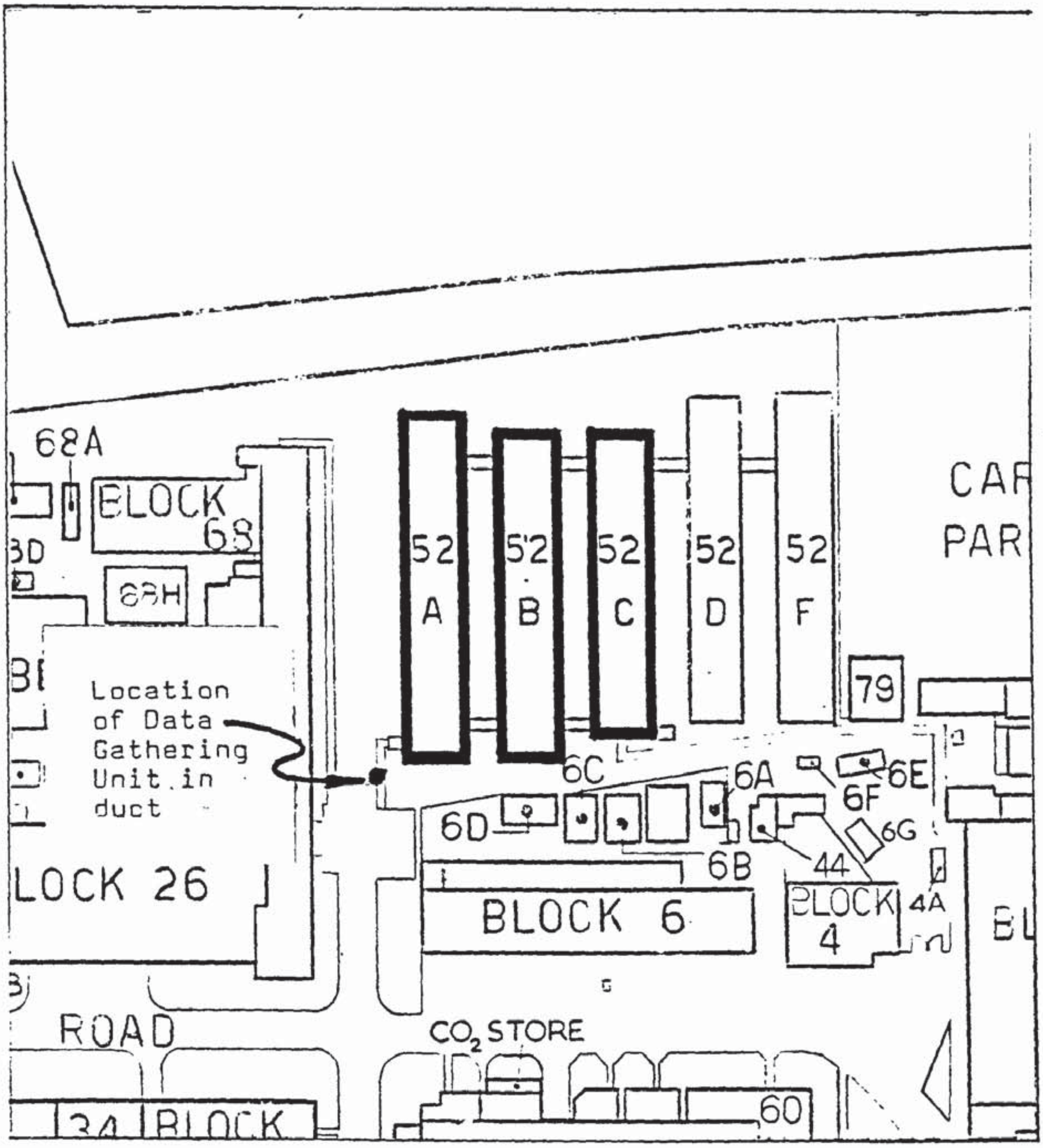
HEATING AREA : 31

Data gathering unit input	System input	Function
0	184	
1	185	
2	186	
3	187	
4	188	
5	189	
6	190	To
7	191	FLOW



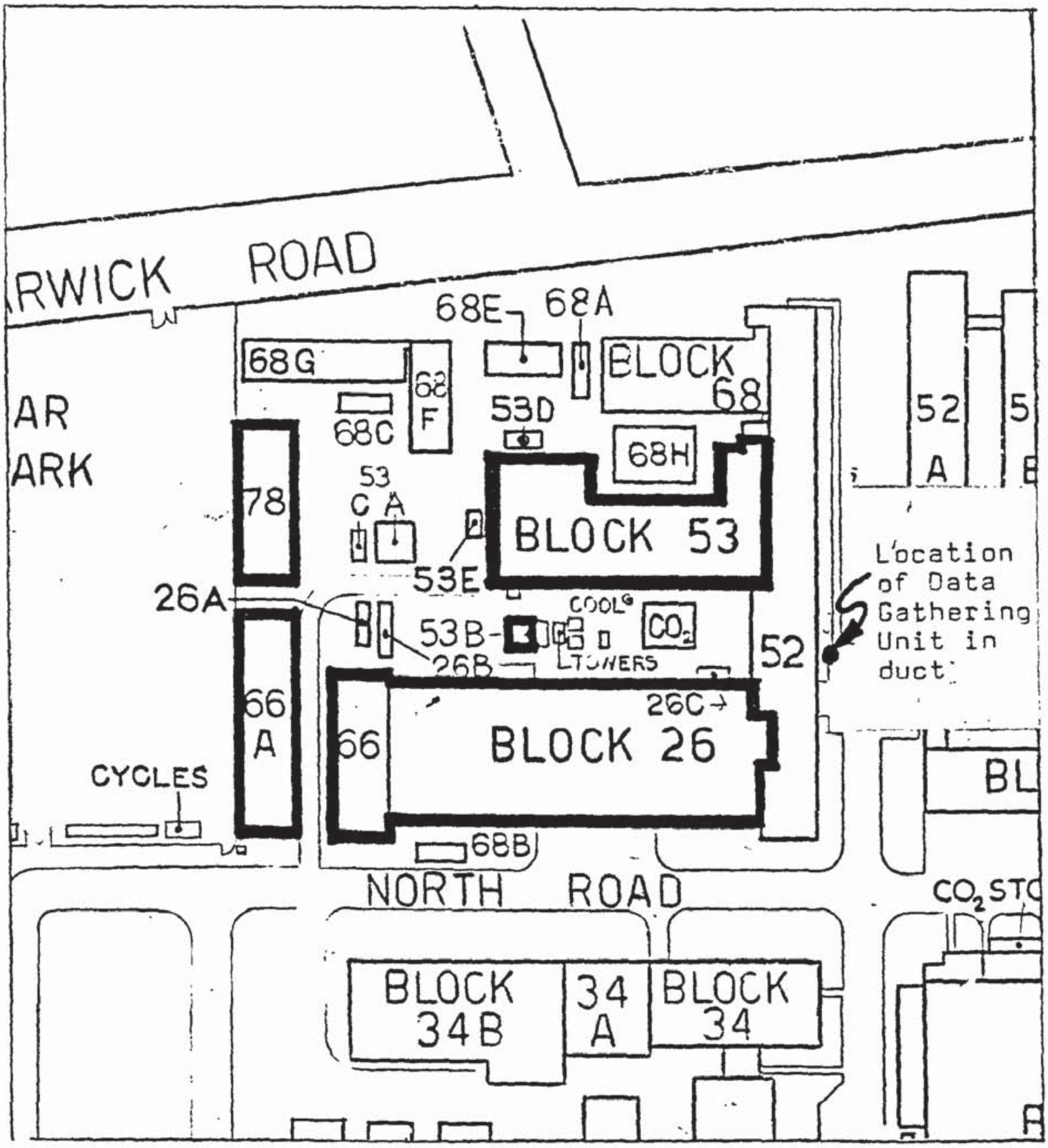
HEATING AREA : 32

Data gathering unit input	System input	Function
0	192	
1	193	
2	194	To
3	195	FLOW
4		
5		
6		
7		



HEATING AREA : 33

Data gathering unit input	System input	Function
0	200	
1	201	
2	202	To
3	203	FLOW
4		
5		
6		
7		



HEATING AREA : 34

Data gathering unit input	System input	Function
0	208	
1	209	
2	210	TD
3	211	FLOW (INCLUDES HEATING AREA 10)
4		
5		
6		
7		

APPENDIX 2

QUOTATION FROM FISHER CONTROLS LIMITED FOR HEAT METERS USING ORIFICE PLATE FLOW METERS

Customer: GEC Power Engineering Ltd.,	Quotation No. / Contract No.	571/1/18967/DYER/CAW.

Item	Quantity	
		<u>BTU MEASURING LOOPS (EACH LOOP COMPRISING:)</u>
1	1	Carrier Ring Orifice Plates or Orifice Flange Assemblies (the type depends on the nominal pipe diameter). Carrier Ring Orifice Assemblies incorporate pressure tapping points and are suitable for mounting between the flanges of the pipe in a position to our approval. Orifice Flange Assemblies incorporate pressure tapping points and are suitable for mounting between the pipe ends in a position of our approval. Nominal pipe diameters between 1½ and 8 inches.
2	1 pr	Pipeline Fittings Model 405-30. The fittings incorporate stop cocks for use with the above Orifice Plates.
3	1	Barton D.P. Flow Transmitter Model 4523. D.P. Range: 0-400"WG. Complete with Square Root Extraction Module. Output: 4-20 mA dc (Linear). D.P. Unit: Model 199. Static Pressure Rating: 2500 p.s.i.g. Body Material: Carbon Steel. Complete with Manifold Assembly Model 1099C. Mounting: 2" Standpipe.
4	1	Power Supply Units Model 4551. Output Voltage: 32 volts dc ± 2 volts. To supply 4523 Transmitter Unit. Retransmission Signal Output: 0-10 mA dc. Supply Voltage: 110 or 240 volts 50 Hz.

Customer: GEC Power Engineering Ltd.	Quotation No. / Contract No.	571/1/18967/DYER/CAW

Item	Quantity	
5	2	Resistance Thermometer Assemblies, Model 36SS. Platinum wound element on glazed former. Pocket fabricated in stainless steel. Extension in mild steel. Flanged connection. Distance Below Flange: 6 inches. The assembly comes complete with a die cast aluminium terminal head.
6	1	Bridge Unit supplying power to the Series 36SS Resistance Thermometers.
7	1	Millivolt to current converter Model AMT213.
8	1	Integrator Unit Model ACC353. Input: 0-10 mA dc. The Integrator is an 8 digit non reset.
		<u>SINGLE LOOP PRICE: £1607.00</u>. Quotation Notes 1 to 5 apply.

QUOTATION NOTES

1. Installation and Commissioning are not included in this quotation although we should be pleased to provide either or both of these services if required subject to a separate quotation.

2. This quotation is for the items listed. Any additional equipment, e.g. mains cable etc., we would be pleased to supply at extra cost.

3. One set of Installation and Maintenance Instructions would be supplied with each set of equipment. Additional copies would be supplied at extra cost.

4. The equipment offered, where applicable, is designed to operate from a 100/120 volt or 200/250 volts 40/60Hz single phase supply. Please state exact voltage required at time of order.

5. The equipment if finished in our standard production colours and paint specification. Special finishes may be supplied at extra cost and may result in an extension to the delivery date mentioned above.

APPENDIX 3

DESIGN CALCULATIONS FOR THE VENTURI TUBE FLOW ELEMENTS USED FOR HEAT METERING ON THE GEC WHETSTONE SITE

DESIGN CALCULATIONS FOR THE VENTURI TUBE FLOW ELEMENTS TO BE USED FOR HEAT METERING ON THE G.E.C. WHETSTONE SITE

September 1980

M. Roberts

Plant & Buildings Department
G.E.C. Gas Turbines Ltd.
Whetstone

This document contains the calculations of the venturi tube dimensions which are to be used for heat metering on the G.E.C. Whetstone Site. All calculations and extracts of data are from British Standard 1042 : Part 1 : 1964 (Methods for the measurement of fluid flow in pipes : Orifice plates, nozzles, and venturi tubes) and are specific to the HPHW heating system on the Whetstone Site.

PROCEDURE FOR DESIGN CALCULATIONS (From B.S. 1042: Part 1: 1964)

1. Select the type of device appropriate to the particular application (see Clauses 38–39).

2. Check the suitability of the type chosen by reference to the range of application given in the relevant Section Seven to Fourteen.

3. Determine the pipe diameter D inches if the device is to be installed in an existing pipeline. Otherwise choose a suitable pipe size.

4. For an existing pipeline, determine the number of diameters of straight pipeline available upstream of the device and from Subclauses 47*b* and *e* and Table 8 estimate the maximum permissible value of the area ratio.

5. Express the rate of flow in the units adopted in the standard (lb/h, ft^3/h or UKgal/h) (see Tables 13 and 14 in Appendix A). For continuous metering take for the subsequent calculations a rate of flow equal to 0·7 of the maximum rate of flow to be handled.

6. Determine the upstream pressure, p lbf/in^2 gauge; the local barometric pressure, p_b lbf/in^2; and obtain the absolute upstream pressure P lbf/in^2 $(= p + p_b)$ (Clause 23).

7. Determine the upstream temperature, t°F and add 459·67° to obtain the absolute upstream temperature T°R (Clause 24).

8. Correct the pipe diameter for thermal expansion to obtain the value at the working conditions (Clause 21).

9. Determine the density of the fluid under working conditions, ρ lb/ft³.

10. Determine the viscosity of the fluid under working conditions, μ poise.

11. Determine for gases the specific heat ratio, γ (Clause 29).

12. Convert the rate of flow, if in volume units, from reference to working conditions (Subclause 13b, Appendix A. and Table 14.

13. Select a suitable value of the pressure difference expressed in inH_2O. For continuous metering, remember that the pressure difference for the maximum rate of flow will be twice that for a flow of 0·7 of the maximum.

14. Check that the chosen value of the pressure difference (inH_2O) is less than 5·5 times the absolute upstream pressure (lbf/in^2).

15. Calculate the quantity N from Equation 10 (Subclause 14*a*).

16. Obtain an approximate value of m by assuming that CmE is equal to N (that is, taking both Z and ϵ to be unity) and by reading the value of m corresponding to CmE from Fig. 3. Calculate also an approximate value of d/D $(= \sqrt{(m)})$. Alternatively, for square-edged orifice plates only obtain an approximate value of mE by dividing N by 0·606 and read an approximate value of d/D from the chart (Appendix J) at the back of the standard (Clause 15). For conical-entrance orifice plates only, an exact value of mE is given by dividing N by the discharge coefficient given in Section Ten, and an exact value of d/D is then obtained from the chart (Appendix J). Omit the following steps 19–26 inclusive.

17. Check that a device of the type chosen and having the approximate value of d/D or m satisfies the requirements of the relevant Section Seven to Fourteen and also the requirements of Section Six (Clauses 45–52). Otherwise select a different value for the pressure difference and repeat steps 14 to 16 inclusive. Remember when selecting a new value for the pressure difference that the pressure difference is approximately proportional to the fourth power of the orifice or throat diameter.

18. The approximate value of d may be taken as a guide to the choice of a suitable value for d and the rate of flow may then be calculated for this chosen value by the procedure given above under ' Steps in the calculation of the Rate of Flow '.

Alternatively the exact value of d required for the chosen rate of flow and pressure difference may be calculated by the procedure given below.

19. Calculate the Reynolds number R_d from the approximate value of d by means of Equation 13, Subclause 14a. For quarter-circle orifice plates, check that R_d is greater than the lower limit given in Fig. 45 and omit the following steps 20–23 inclusive.

20. Obtain the values of Z_R and Z_D from the relevant Section Seven to Fourteen. For orifice plates with flange tappings the combined multiplier Z $(= Z_R Z_D)$ is given in Fig. 41.

21. Obtain for gases or vapours the value of the expansibility factor ϵ from the relevant section.

22. Calculate an improved value of CmE by dividing N by $Z\epsilon$.

23. Obtain an improved value of m from this value of CmE by means of Fig. 3.

24. Obtain the basic coefficient C for the improved value of m from the relevant section.

25. Calculate mE by dividing the improved value of CmE by C.

26. Obtain the value of d/D from mE by means of the chart (Appendix J) at the back of the standard.

27. Calculate the value of d from d/D using the pipe diameter at working conditions.

28. Correct the value of d for thermal expansion to obtain the value at room temperature (Subclause 20a).

29. Correct the value of d at room temperature for presence of a drain hole if any (Subclause 20b and note under Step 15, Appendix B1).

30. Check that a device having the final calculated orifice or throat diameter satisfies the requirements of the relevant Section Seven to Fourteen and also the requirements of Section Six (Clauses 45–52).

NOMENCLATURE

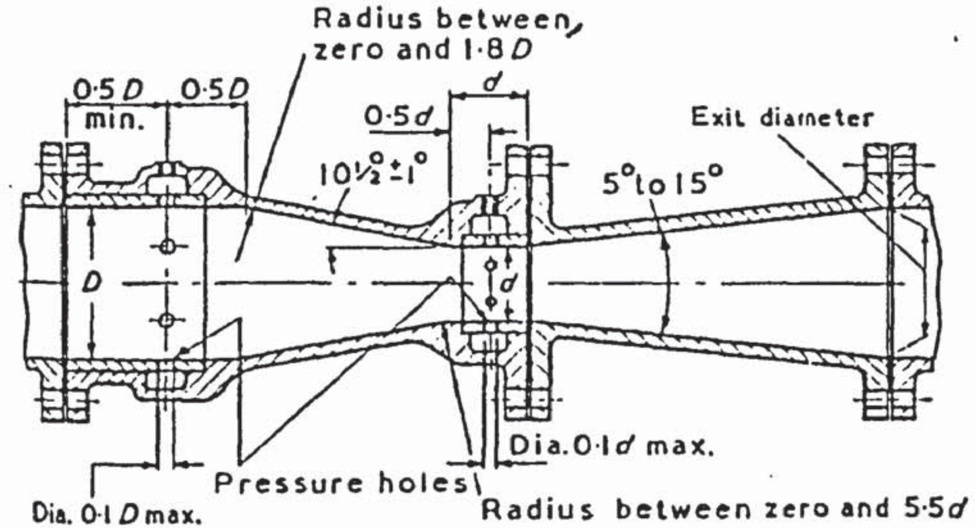
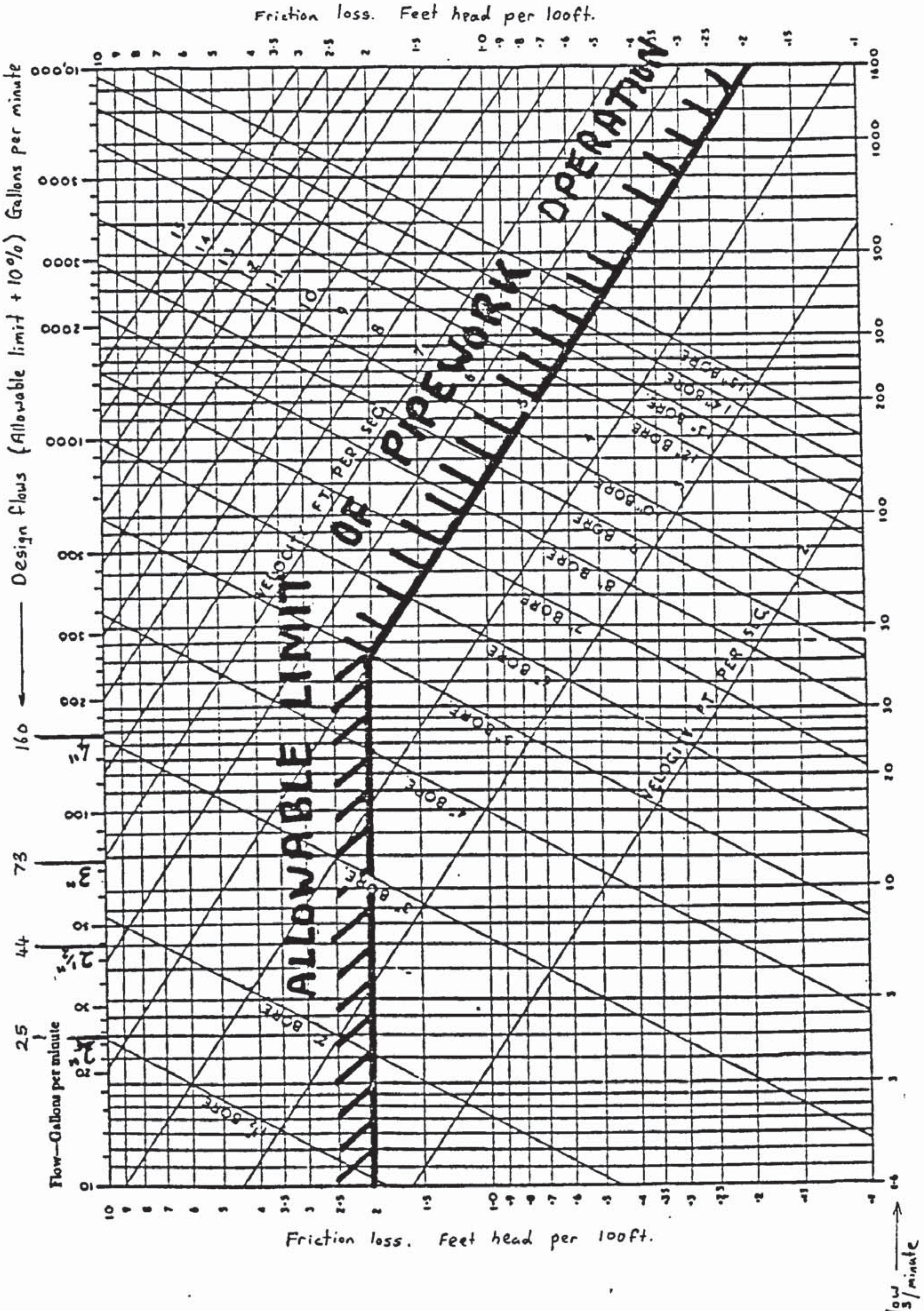


Fig. 51. Venturi tube

Friction Loss Diagram for Clean Water Flowing in Steel Pipes



DATA

(1) Density of HPHW at 290°F, 200 psia.

b. Temperature range 32°F to 1000°F

Temp. (°F)	Pressure 25	50	100	250	500	750	1000	1500
32	62·50	62·58	62·74	63·20	63·94	64·63	65·29	66·48
60	62·44	62·52	62·66	63·08	63·77	64·40	65·0	66·2
100	62·07	62·14	62·28	62·68	63·32	63·9	61·5	65·6
150	61·27	61·34	61·48	61·88	62·5	63·2	63·7	64·9
200	60·20	60·27	60·42	60·84	61·5	62·1	62·7	63·9
212	59·92	59·99	60·13	60·6	61·2	61·8	62·4	63·6
300	57·4	57·5	57·6	58·1	58·7	59·5	60·2	61·4
400	—	53·8	54·0	54·5	55·5	56·5	57·4	58·4
500	—	—	49·3	50·1	51·1	51·9	53·9	54·3
600	—	—	—	44·6	45·8	46·8	47·7	49·3
700	—	—	—	—	36·5	39·5	40·1	41·6
800	—	—	—	—	—	—	33·7	36·5
900	—	—	—	—	—	—	23·6	32·2
1000	—	—	—	—	—	—	—	28·4

NOTE. The values given in Table 3*a* are accurate to better than ± 0·05 per cent. In Table 3*b* however the accuracy rapidly diminishes as the temperature and pressure increase; at 500°F and 500 atm the tolerance may be taken as ± ½ per cent and at the extreme values given the tolerance should be taken as about ±2 per cent.

It should be noted that the above values relate to distilled water; the density of normal water, containing salts in solution, may be 0·1 per cent or more higher than that of distilled water.

* From *Properties of ordinary water substance*, by N. E. Dorsey. American Chemical Society Monograph Series (New York. Reinhold), 1940. See also *Extension of tables of density of distilled water*, by E. A. Spencer. (East Kilbride, Glasgow National Engineering ...). Fluids Memo No. 83, 1959.

By interpolation : $\rho = 57.8$ lb/ft³ $[1/\rho = 0.0173$ ft³/lb$]$

This checks with steam tables where specific volume (v) $[v = 1/\rho]$ for saturated liquid 290°F is 0.0174 ft³/lb.

(2) Viscosity of HPHW at 290°F 200 psia

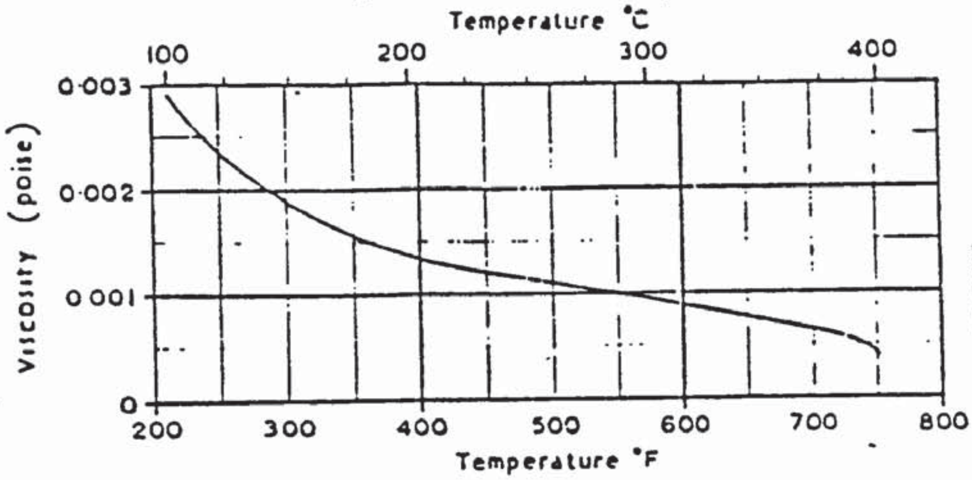


Fig. 16. Viscosity of water from 212° to 750°F at saturation pressure

The tolerance increases from about ±1 per cent at 212°F to about ±5 per cent at 750°F (from same source as Fig. 15)

Viscosity of liquids barely changes with pressure.
(B.S. 1042, Part I, 1964, Clause 28)

μ = 0.002 poise

(3) Thermal Expansion

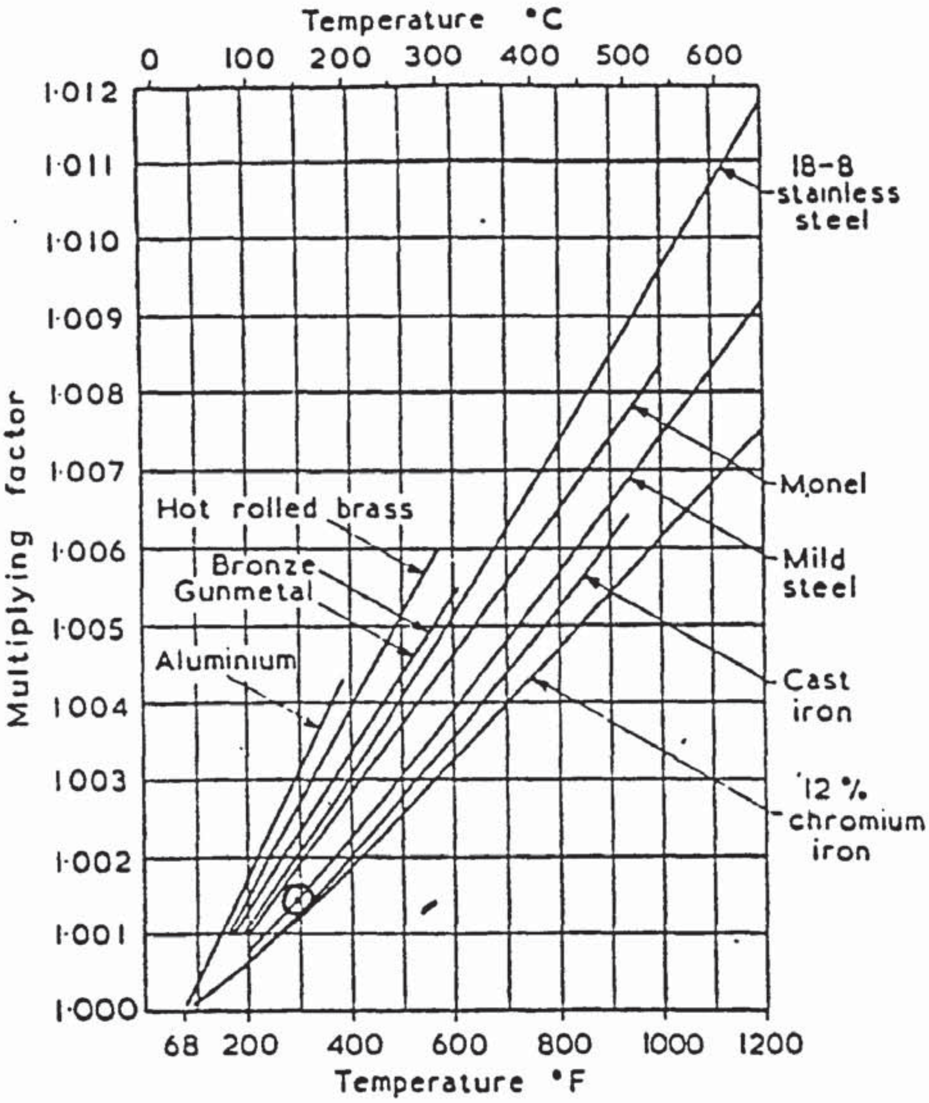


Fig. 5. Multiplying factors for thermal expansion

Multiolying factor for mild steel at 290°F = 1·0015

[Reciprocal = 0·9985]

(4) Expansability Factor for HPHW

$\in$ = 1 (ie. HPHW is incompressible)

COMPUTATIONAL CHARTS

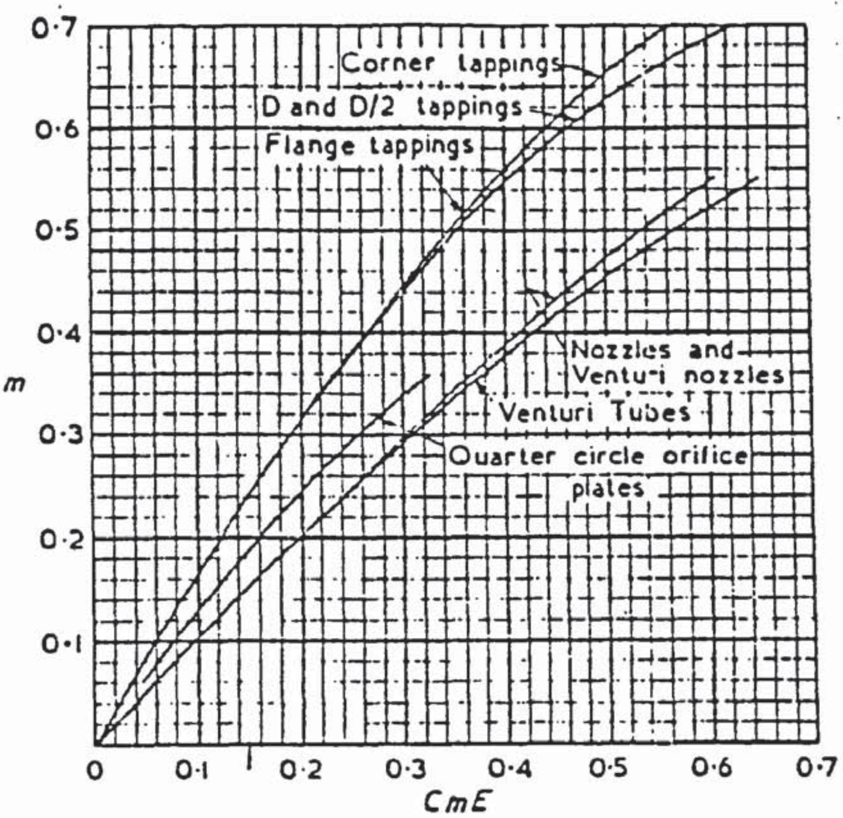


Fig. 3. Values of m plotted against CmE
(for use only in calculation of orifice or throat diameter)

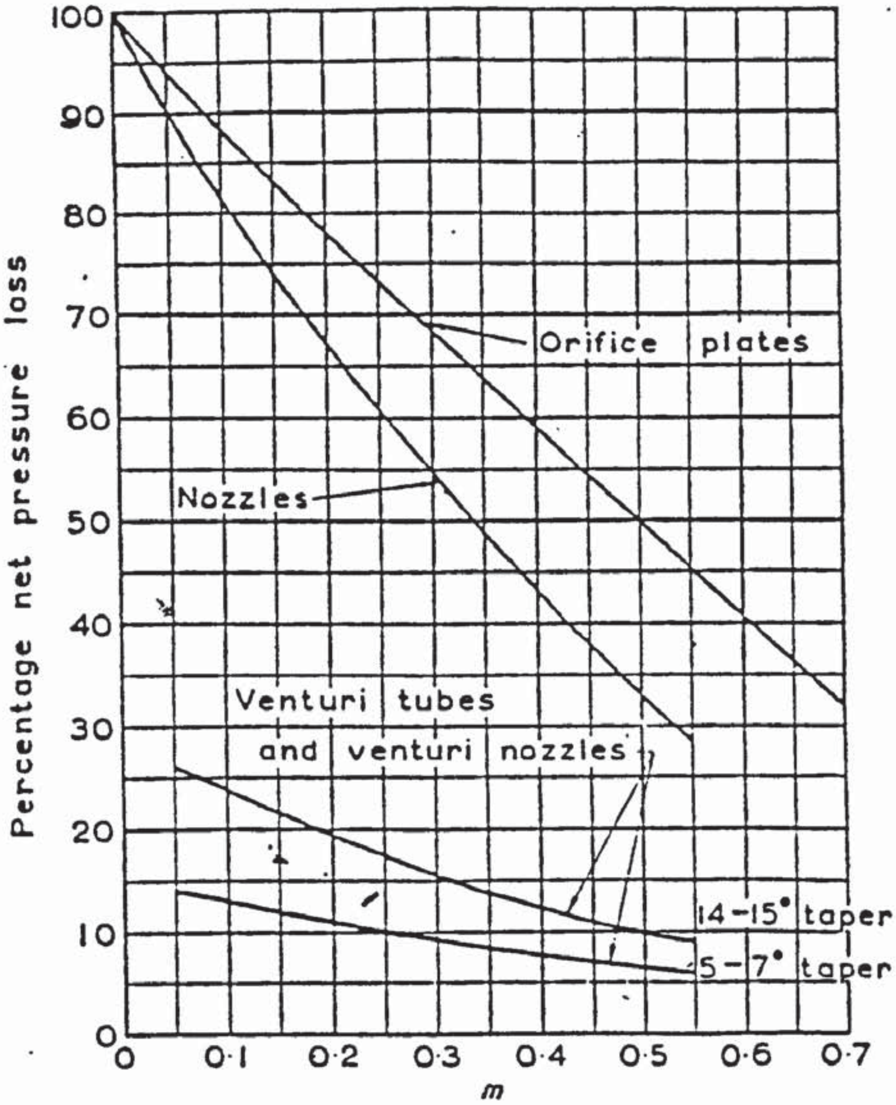
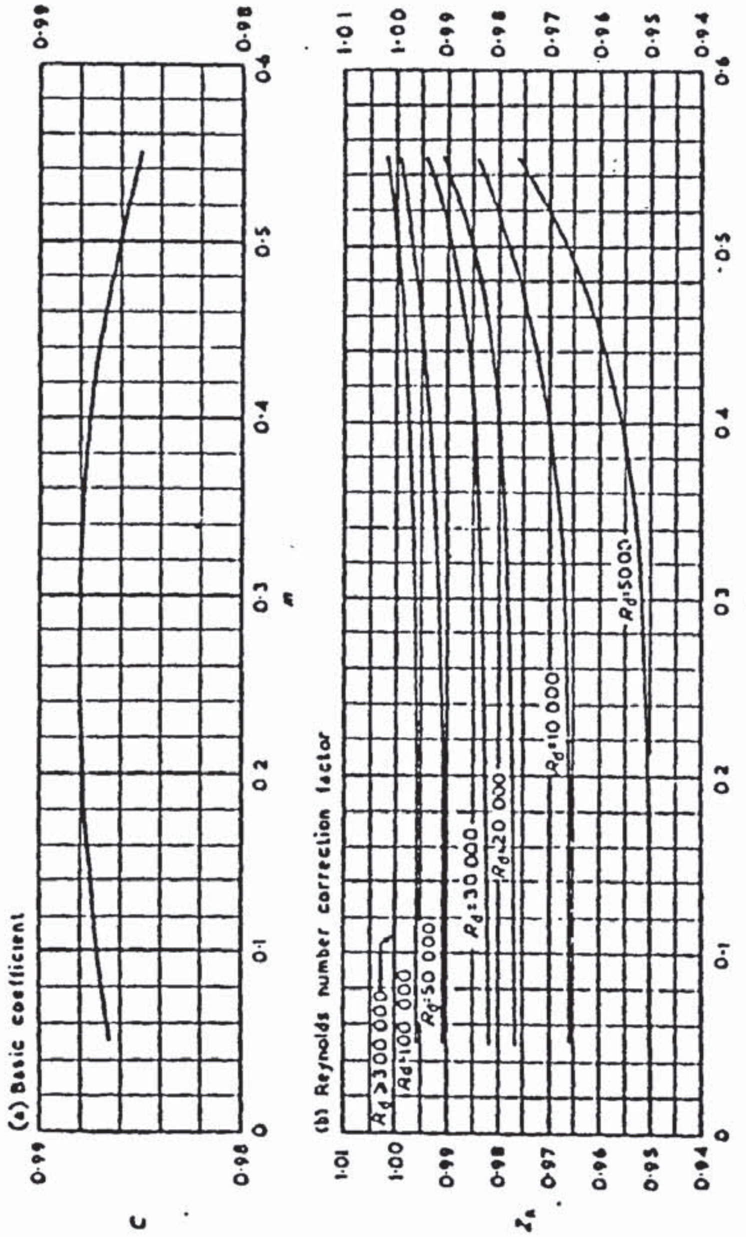


Fig. 4. Net pressure loss as a percentage of pressure difference (see also Fig. 62)

NOTE. Despite appearances, the net pressure loss is the same for orifice plates and nozzles for the same rate of flow in the same size of pipe at the same pressure difference (see Clause 10).

COMPUTATIONAL CHARTS



COMPUTATIONAL CHARTS

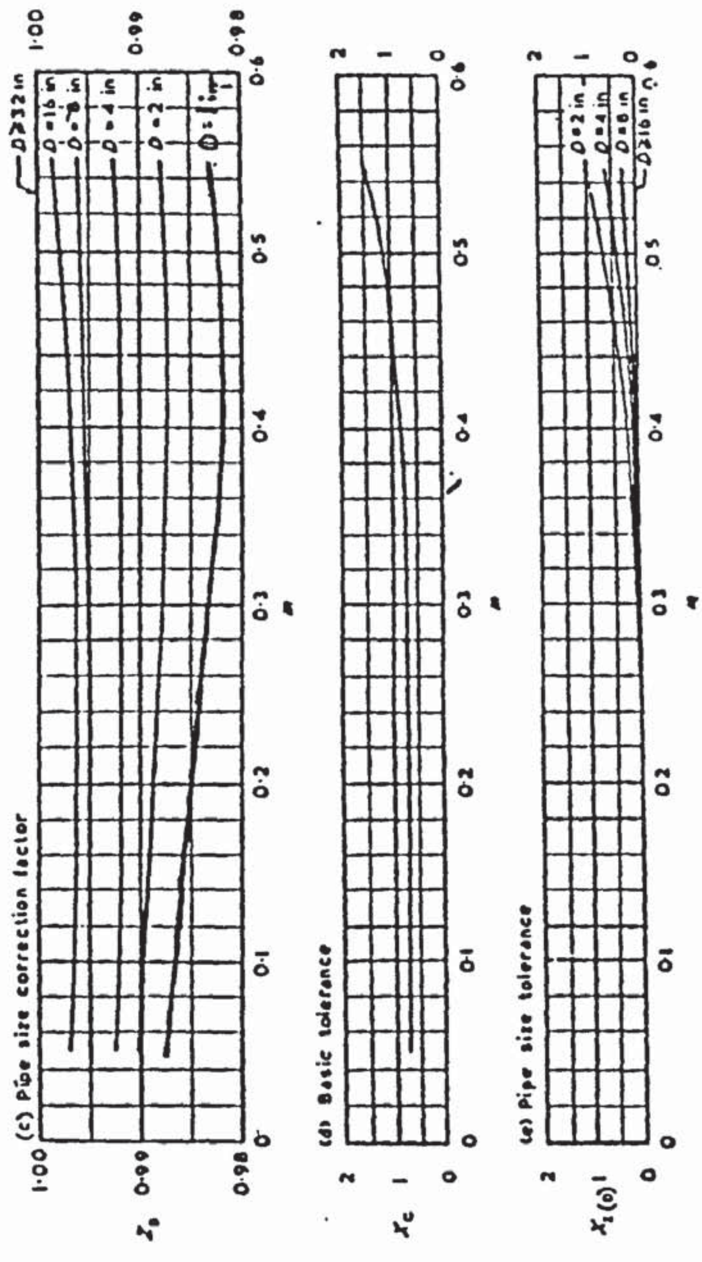
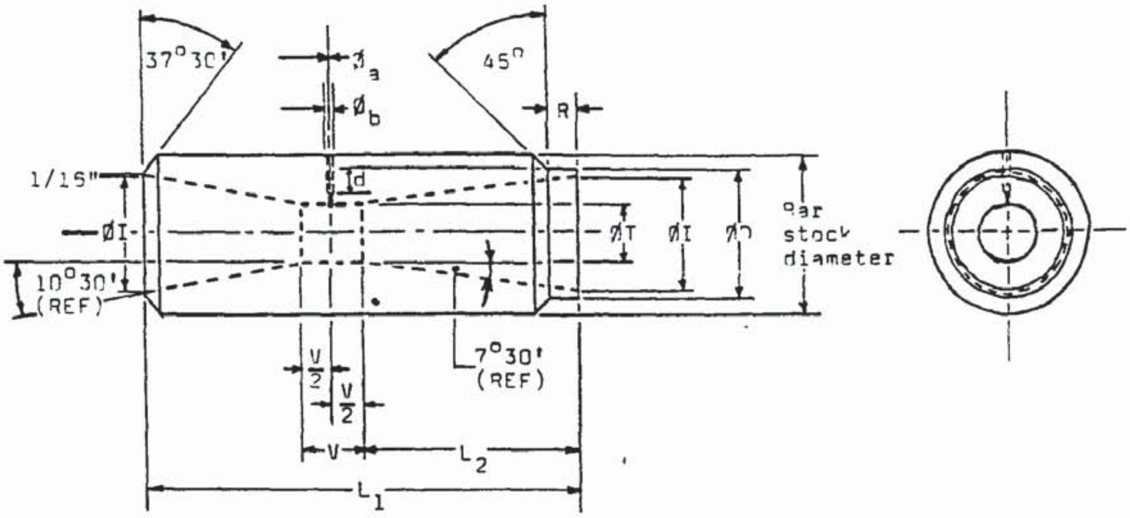


Fig. 52 Data for venturi tube

CALCULATION

PIPE BORE (inches)	1	1¼	1½	2	2½	3	4
DESIGN RATE OF FLOW (gpm)	5	7.5	11	25	44	73	160
— " — (lb/h)	2784	4175	6124	13920	24500	40650	89080
SIZE VENTURI ON 0.707 MASS FLOW RATE (lb/h)	1969	2952	4330	9842	17324	28744	62990
IE HALF FULL SCALE DIFFERENTIAL PRESSURE READING OF 50" w.g. (in. w.g.)	25	25	25	25	25	25	25
PIPE DIAMETER AT 290°F (inches)	1.0015	1.252	1.502	2.003	2.504	3.0045	4.006
$N = \frac{W}{359.2\, D^2 \sqrt{h\rho}}$	0.144	0.138	0.141	0.180	0.202	0.233	0.287
PROVISIONAL $CmE = N$	0.144	0.138	0.141	0.180	0.202	0.233	0.287
m (FROM FIG. (3))	0.146	0.140	0.142	0.182	0.203	0.235	0.284
$R_d = \frac{W}{15.8\mu\, D \sqrt{m}}$	162800	199400	242100	364500	485900	624500	933700
Z_R (FROM FIG. (52(b)))	0.997	0.998	0.999	1.00	1.00	1.00	1.00
Z_D (FROM FIG (52(c)))	0.986	0.987	0.988	0.988	0.990	0.990	0.993
$Z = Z_R . Z_D$	0.983	0.985	0.987	0.988	0.990	0.990	0.993
ϵ	1	1	1	1	1	1	1
IMPROVED $CmE = \frac{N}{Z\epsilon}$	0.146	0.140	0.143	0.182	0.204	0.235	0.289
IMPROVED m (FROM FIG.(3))	0.15	0.142	0.147	0.187	0.205	0.235	0.288
C (FROM FIG. (52(a)))	0.9875	0.9870	0.9875	0.988	0.988	0.988	0.988
$mE = \frac{CmE}{C}$	0.148	0.142	0.145	0.184	0.206	0.238	0.293
$d = D\left[\frac{(mE)^2}{1+(mE)^2}\right]^{0.25}$ (in) [AT MACHINING TEMPERATURE]	0.38	0.47	0.57	0.85	1.12	1.44	2.12
NET PRESSURE DROP (in. w.g.) (FROM FIG. (4)).	9	8.5	9	8	7.5	7	6



REF : Angles marked REF are for guidance only

Material : Bright drawn stock steel bar

Finish : Internal surfaces $\overset{32}{\nabla}$ or $\overset{N6}{\nabla}$

	Venturi size	BS pipe	1"	1¼"	1½"	2"	2½"	3"	4"
Design parameters	Full scale flow [FLOW CONST]	lb/h	2784	4175	6124	13920	24500	40650	89080
	Full scale pressure differential	in H_2O	50	50	50	50	50	50	50
	Net head loss	in H_2O	9	9	9	8	8	7	6
Machining dimensions	ØT	inches mm	0.380 9.65	0.470 11.95	0.570 14.5	0.850 21.6	1.120 28.45	1.440 36.5	2.120 53.85
	ØI	inches mm	1.025 26.0	1.369 34.75	1.585 40.3	2.023 51.6	2.649 67.25	3.116 79.15	4.076 103.55
	ØD	inches mm	1.344 34.1	1.588 42.9	1.906 48.4	2.375 60.3	3.000 76.2	3.500 88.9	4.500 114.3
	L_1	inches mm	4.62 115.5	6.3 161.0	7.16 182.5	8.47 214.5	11.05 280.5	12.34 313.5	14.83 376.5
	L_2	inches mm	2.50 62.0	3.41 87.0	3.85 98.0	4.45 113.0	5.8 147.0	6.37 162.0	7.43 189.0
	V	inches mm	0.38 9.5	0.47 12.0	0.57 14.5	0.85 21.5	1.12 28.5	1.44 36.5	2.12 54.0
	R	inches mm	0.40 10.0	0.5 12.0	0.5 12.0	0.65 16.0	0.65 16.0	0.65 16.0	0.8 21.0
	$Ø_a$	Drill Ø inches	1/16	1/16	1/16	3/32	3/32	1/8	3/16
	$Ø_b$	Drill Ø inches	3/16	3/16	1/4	1/4	1/4	1/4	1/4
	d	inches mm	0.3 7.0	0.4 10.0	0.5 12.0	0.5 12.0	0.7 18.0	0.7 18.0	0.8 21.0
Pipe fitting dimensions	Upstream length of pipe	inches	18.5	23.0	27.75	37.0	46.25	55.5	74.0
	Upstream pressure tapping from throat tapping hole	inches	2.45	3.3	3.75	4.6	5.95	6.75	8.35
	Drill diameter for upstream tapping	Drill Ø inches	1/16	1/16	1/16	3/32	3/32	1/8	3/16

Tolerances : Turned diameters : +0.005 inches +0.1 mm
Lengths : ±0.05 inches ±1.0 mm
Drilled diameters : - As drilled
Drilling depths : +0.0, -0.1 inches +0.0, -2.5 mm

VENTURI TUBE FLOW ELEMENT

APPENDIX 4

ACCURACY OF THE 2 INCH TEST VENTURI CALCULATED BY BS 1042 PROCEDURE

APPENDIX 4

ACCURACY OF THE 2 INCH TEST VENTURI CALCULATED BY BS 1042 PROCEDURE

From BS 1042, Section 4:

Tolerance (%) on mass and volume flow rate, X_w, is given by:

$$X_w = \left[X_c^2+X_{Z(R)}^2+X_{Z(D)}^2+X_{\epsilon}^2+\left(\frac{2}{1-m^2}\right)^2 X_d^2+\left(\frac{2m^2}{1-m^2}\right)^2 X_D^2+\frac{1}{4}(X_{\rho}^2+X_h^2)\right]^{0.5}$$

where and for the 2 inch test venturi:

X_c = Tolerance on discharge coefficient = 0.7% (from BS 1042 Clause 93(a)).

$X_{Z(R)}$ = Tolerance on Reynolds number correction factor = 0% (from BS 1042 Clause 93(B)).

$X_{Z(D)}$ = Tolerance on pipe viza correction factor = 0% (from BS 1042 Clause 93(c)).

X_{ϵ} = Tolerance on expansibility factor = 0% (from BS 1042 Clause 93(d)).

X_d = Tolerance on throat bore = 0.6%
(Machining tolerance from Appendix 3).

X_D = Tolerance on pipe diameter = 3.2%
(Manufacturing tolerance from BS 1387 for BS pipe)

X_ρ = Tolerance on fluid density = 0.5%
(from data in Appendix (3)).

X_h = Tolerance on pressure differential reading = 2%
(Quoted total error for pressure differential meter a full scale deflection of 50 inches water gauge. i.e. Also the differential produced by the venturi at design flow rate).

m = 0.182 (from Appendix 3).

giving X_w = 1.77% tolerance on mass and volume flow rate

APPENDIX 5

SPECIMEN HEAT METERING PRINT-OUT

HEAT CONSUMPTION GEC WHETSTONE   PERIOD 16.00 24 JANUARY 1983
TO 10.00 25 JANUARY 1983

DTL

EFF	HEATING AREA	MAX HEAT DEMAND BTU/HR	HEAT CONSUMED THERMS
0.16	01	31012	3.66
1.00	02	581204	43.10
0.05	03	13811	.13
0.47	05	563804	48.84
0.38	06	10498297	1006.19
0.37	11	1368295	151.76
1.00	12	5518002	260.18
0.61	13	305653	44.21
0.41	15		.00
0.04	17		.00
0.32	19	2317870	144.63
0.64	21	518855	15.44
0.98	22	343323	33.85
0.79	23	293538	2.97
0.75	24	312349	129.55
0.43	25	350074	37.35
0.09	26		.00
0.24	27	1015327	42.10
0.93	29	135487	28.35
1.00	30	562955	31.66
1.00	31	3645004	206.14
0.34	32	2665013	78.59
0.06	34		.00
TOTALS		32794689	2529.88

ESL

EFF	HEATING AREA	MAX HEAT DEMAND BTU/HR	HEAT CONSUMED THERMS
0.53	05	754194	55.08
1.00	07	4222293	233.90
0.27	08	757232	72.46
1.00	09		.00
0.36	10	367513	34.81
0.36	11	130385	26.09
1.00	14	95985	10.64
1.00	15	1071441	111.01
0.35	16	239142	6.79
0.27	34		.00
TOTALS		3068174	550.81

MEL

EFF	HEATING AREA	MAX HEAT DEMAND BTU/HR	HEAT CONSUMED THERMS
0.28	01	141781	5.41
0.39	03	137730	1.54
0.23	04	126126	3.84
0.34	15		.00
0.43	16	293603	9.35
0.20	24	216626	34.54
0.37	25		.00
TOTALS		396068	54.70

DYL

APP	HEATING AREA	MAX HEAT DEMAND BTU/HR	HEAT CONSUMED THERMS
0.04	15		.00
0.14	25	276802	29.53
0.25	33		.00
TOTALS		276802	29.53

MCS

APP	HEATING AREA	MAX HEAT DEMAND BTU/HR	HEAT CONSUMED THERMS
0.55	04	301605	9.20
TOTALS		301605	9.20

NNC

APP	HEATING AREA	MAX HEAT DEMAND BTU/HR	HEAT CONSUMED THERMS
0.56	03	154669	2.21
0.20	04	109674	3.34
0.63	08	1300208	169.07
0.03	13	15032	2.17
0.93	17		.00
0.17	18	113154	3.30
1.00	20	932371	19.64
0.33	21	312097	7.96
0.07	25	56958	6.08
0.97	[illegible]	590132	33.64
0.22	34		.00
TOTALS		3694350	247.64

EST

APP	HEATING AREA	MAX HEAT DEMAND BTU/HR	HEAT CONSUMED THERMS
0.56	01	253563	12.82
0.02	04	10967	.33
0.02	06	214250	20.53
0.04	10	40313	1.45
0.03	11	60875	10.97
0.21	[illegible]		.00
0.07	[illegible]		.00
0.05	15	34162	.37
0.08	[illegible]	101553	12.57
0.03	21	23008	.72
0.02	22	7006	.63
0.21	23	75029	.79
0.09	24	54156	8.63
0.16	25	130260	13.90
0.29	26		.00
0.15	[illegible]	193395	8.02
0.07	[illegible]	14714	2.13
1.00	[illegible]	745485	54.34
0.06	[illegible]	154149	5.01
0.03	33	21344	1.04
0.05	34		.00
TOTALS		2303238	154.97

APPENDIX 6

MATRIX OF DATA

FOR

GEC WHETSTONE HEAT METERING

MATRIX OF DATA FOR GEC WHETSTONE HEAT METERING

HEAT AREA	ADDR. FLOW	ADDR. TD	FLOW ZERO	FLOW CONST	FLOW INDEX	TD CONST	HEAT AREAS SUBTRACTED			APPORTION UNIT	APP
00					1.00	.00	00	00	00	00	0.00
										00	0.00
										00	0.00
										00	0.00
01	53	52		2784	130.00	1.00	00	00	00	01	0.15
										03	0.28
										07	0.56
										00	0.00
02	23	20	11	19686	172.00	1.00	01	00	00	01	1.00
										00	0.00
										00	0.00
										00	0.00
03	27	25		3661	172.00	1.00	00	00	00	01	0.05
										03	0.39
										06	0.56
										00	0.00
04	31	30		5661	172.00	1.00	00	00	00	03	0.23
										05	0.55
										06	0.20
										07	0.02
05	35	34		19686	172.00	1.00	00	00	00	01	0.47
										02	0.53
										00	0.00
										00	0.00
06	43	42	14	59090	130.00	1.00	00	00	00	01	0.98
										07	0.02
										00	0.00
										00	0.00
07	51	50	14	40650	130.00	1.00	00	00	00	02	1.00
										00	0.00
										00	0.00
										00	0.00
08	59	58		24500	130.00	1.00	00	00	00	02	0.27
										06	0.73
										00	0.00
										00	0.00
09	67	66		4175	130.00	1.00	00	00	00	02	1.00
										00	0.00
										00	0.00
										00	0.00
10	75	74		13920	130.00	1.00	00	00	00	02	0.96
										07	0.04
										00	0.00
										00	0.00
11	33	32		34000	130.00	1.00	00	00	00	01	0.97
										07	0.03
										00	0.00
										00	0.00

12	31	30		34000	190.00	1.00	11	00	00	01 00 00 00	1.00 0.00 0.00 0.00
13	91	89		55700	190.00	1.00	00	00	00	01 02 06 00	0.61 0.36 0.03 0.00
14	99	98		18670	190.00	1.00	00	00	00	02 00 00 00	1.00 0.00 0.00 0.00
15	107	106		55700	190.00	1.00	00	00	00	02 00 00 00	1.00 0.00 0.00 0.00
16	115	114		34000	190.00	1.00	00	00	00	01 00 00 00	0.00 0.00 0.00 0.00
17	11	10		40000	190.00	1.00	00	00	00	01 06 07 00	0.04 0.93 0.03 0.00
18	123	122		13920	190.00	1.00	00	00	00	02 03 06 07	0.35 0.43 0.17 0.05
19	131	130		24500	190.00	1.00	00	00	00	01 07 00 00	0.92 0.08 0.00 0.00
20	15	14	38	24500	190.00	1.00	00	00	00	06 00 00 00	1.00 0.00 0.00 0.00
21	139	138		13920	190.00	1.00	00	00	00	01 06 07 00	0.64 0.33 0.03 0.00
22	145	144		40650	190.00	1.00	00	00	00	01 07 00 00	0.98 0.02 0.00 0.00
23	147	146		2764	190.00	1.00	00	00	00	01 07 00 00	0.79 0.21 0.00 0.00
24	149	148		40650	190.00	1.00	00	00	00	01 03 07 00	0.75 0.20 0.05 0.00

25	155	154	39080	130.00	1.00	00	00	00	01	0.43
									04	0.34
									06	0.07
									07	0.16
26	163	162	34000	130.00	1.00	00	00	00	01	0.09
									03	0.37
									04	0.25
									07	0.29
27	171	170	13920	190.00	1.00	00	00	00	01	0.84
									07	0.16
									00	0.00
									00	0.00
28	177	176	6124	130.00	1.00	00	00	00	01	0.93
									07	0.07
									00	0.00
									00	0.00
29	179	178	13920	190.00	1.00	00	00	00	07	1.00
									00	0.00
									00	0.00
									00	0.00
30	187	186	55700	130.00	1.00	00	00	00	01	1.00
									00	0.00
									00	0.00
									00	0.00
31	191	190	40650	130.00	1.00	00	00	00	01	1.00
									00	0.00
									00	0.00
									00	0.00
32	195	194	24500	130.00	1.00	00	00	00	01	0.94
									07	0.06
									00	0.00
									00	0.00
33	203	202	5124	130.00	1.00	00	00	00	06	0.97
									07	0.03
									00	0.00
									00	0.00
34	211	210	130000	130.00	1.00	10	00	00	01	0.06
									02	0.27
									06	0.62
									07	0.05
35				1.00	.00	00	00	00	00	0.00
									00	0.00
									00	0.00
									00	0.00
36				1.00	.00	00	00	00	00	0.00
									00	0.00
									00	0.00
									00	0.00
37				1.00	.00	00	00	00	00	0.00
									00	0.00
									00	0.00
									00	0.00

38	1.00	.00	00	00	00	00	0.00
						00	0.00
						00	0.00
						00	0.00
39	1.00	.00	00	00	00	00	0.00
						00	0.00
						00	0.00
						00	0.00
40	1.00	.00	00	00	00	00	0.00
						00	0.00
						00	0.00
						00	0.00
41	1.00	.00	00	00	00	00	0.00
						00	0.00
						00	0.00
						00	0.00
42	1.00	.00	00	00	00	00	0.00
						00	0.00
						00	0.00
						00	0.00
43	1.00	.00	00	00	00	00	0.00
						00	0.00
						00	0.00
						00	0.00
44	1.00	.00	00	00	00	00	0.00
						00	0.00
						00	0.00
						00	0.00
45	1.00	.00	00	00	00	00	0.00
						00	0.00
						00	0.00
						00	0.00
46	1.00	.00	00	00	00	00	0.00
						00	0.00
						00	0.00
						00	0.00
47	1.00	.00	00	00	00	00	0.00
						00	0.00
						00	0.00
						00	0.00
48	1.00	.00	00	00	00	00	0.00
						00	0.00
						00	0.00
						00	0.00
49	1.00	.00	00	00	00	00	0.00
						00	0.00
						00	0.00
						00	0.00
50	1.00	.00	00	00	00	00	0.00
						00	0.00
						00	0.00
						00	0.00

51	1.00	.00	00	00	00	00 0.00
						00 0.00
						00 0.00
						00 0.00
52	1.00	.00	00	00	00	00 0.00
						00 0.00
						00 0.00
						00 0.00
53	1.00	.00	00	00	00	00 0.00
						00 0.00
						00 0.00
						00 0.00
54	1.00	.00	00	00	00	00 0.00
						00 0.00
						00 0.00
						00 0.00
55	1.00	.00	00	00	00	00 0.00
						00 0.00
						00 0.00
						00 0.00
56	1.00	.00	00	00	00	00 0.00
						00 0.00
						00 0.00
						00 0.00
57	1.00	.00	00	00	00	00 0.00
						00 0.00
						00 0.00
						00 0.00
58	1.00	.00	00	00	00	00 0.00
						00 0.00
						00 0.00
						00 0.00
59	1.00	.00	00	00	00	00 0.00
						00 0.00
						00 0.00
						00 0.00
60	1.00	.00	00	00	00	00 0.00
						00 0.00
						00 0.00
						00 0.00

APPENDIX 7

COMMISSIONING PROCEDURE FOR HEAT METERING POINTS

APPENDIX 7

COMMISSIONING PROCEDURE FOR HEAT METERING POINTS

The procedure for commissioning a heat metering point has five stages.

(1) Amending the HEAT METERING MATRIX OF DATA

Computational constants for the heat metering facility being commissioned are loaded onto the tape cassette storing the MATRIX OF DATA FOR GEC WHETSTONE HEAT METERING (Appendix 6). The program for undertaking the operation (described in Section 3.6.3) is temporarily loaded into the micro-computer. The computational constants required are listed below.

HEAT AREA — Reference number of the area of the site metered.

ADDR FLOW — The address transmitted in order to acquire the flow measurement for a heat metering point. The tables of system inputs shown throughout Appendix 1 are used to determine the address.

ADDR TD — The address transmitted in order to acquire the flow - return temperature difference for a point.

FLOW ZERO The zero flow pressure difference, as read in hundreths of volts at the input to the CMOS 4051B selector (IC11 shown in Fig. (3.12)). This constant is initially set to zero. The actual reading is obtained after the transducer is made operational. The zero flow condition is simulated by temporarily opening the bypass and closing one of the pressure tapping isolating valves.

FLOW CONST The full scale flow for which the venturi or orifice plate was designed. Values for this constant are shown in Appendix 3.

FLOW INDEX

$$= \frac{A \times B \times D}{B}$$

where:

A = Venturi or orifice plate full scale pressure differential. Usually 50 inches water gauge for venturis and 100 inches for orifice plates.

B = Transducer full scale pressure differential. Transducers with full scales of 70.26 and 140.52 inches wster gauge differential were used for venturi and orifice plate installations respectively.

C = Transducer full scale output voltage. Transducers on standard venturi installations give 12.5mV full scale. Orifice plate transducers give 25mV.

D = Differential operational amplifier gain.

$$\frac{R_D2 + R_D3}{17\ 400} = \frac{R_D4 + R_D5}{17\ 400}$$

R_D2, R_D3, R_D4 and R_D5 were shown in Fig. (A5.10).

The procedure for calculating FLOW INDEX is to first calculate:

$$\text{FLOW INDEX} = \frac{A \times 255}{B}$$

Values of R_D2, R_D3, R_D4 and R_D5 are then calculated using the previous formulae rearranged. The nearest preferred values were selected for these resistors and then FLOW INDEX re-calculated.

In situations conforming to design a FLOW INDEX of 190 is used.

TO CONST — A constant used in conjunction with the gain of the operational amplifier coupling the flow - return temperature difference thermocouple into the data gathering unit.

HEAT AREAS SUBTRACTED — To enable heat consumptions to be derived for an area, each facility can be linked to heat areas which are on branches fed via a given meter. Up to three branches can be subtracted to enable derived heatmetering for an area. The three spaces under HEAT AREAS SUBTRACTED contain the reference numbers (HEAT AREA) of heat areas on branch feeds.

APPORTION UNIT APP — The information contained under these headings is used to apportion a heat area between consumers.

The consumer reference number appears under UNIT.

01 GEC Gas Turbines Limited
02 GEC Energy Systems Limited
03 GEC Mechanical Engineering Laboratory
04 GEC Central Metallurgical Laboratory
05 GEC Midland Computer Service
06 National Nuclear Corporation
07 GEC Power Engineering Limited, Estates Division

The apportionment appears under APP.

(2) <u>Setting ADDRESS Connections and Testing the Data Gathering Unit</u>

The ADDRESS connections on the data gathering unit printed circuit board are set in accordance with binary notation catering for the flow and temperature difference addresses. The address values are shown in Appendix 1.

The data gathering unit is then tested by close-coupling to the central processor sub-system. Test voltages are connected to the inputs and polling sequences executed to check for correct functioning.

(3) Installation of the Data Gathering Unit Printed Circuit Board

The printed circuit board is taken to its allotted location and installed in the enclosure. The electrical mains, signal wire pair, earth bonding and pressure transducer are connected.

(4) Switch-on of the Data Gathering Sub-system

The data gathering unit is switched-on to establish communication with the central processor sub-system in the boiler house. The pressure transducer is then made operational by opening the pressure tapping isolating valves and closing the bypass. The up-stream pressure tapping is opened first to initially pressurise the transducer system.

(5) Calibration of the Thermocouples

The calibration of the thermocouples entails adjusting the gain of the operational amplifier coupling the thermocouple loop to the CMOS 4051B selector (IC11 shown in Fig. (3.12)). The gain is adjusted to return a reading which represents directly the measured temperature difference between flow and return in degrees Fahrenheit.

The gain is governed by the setting of VR_S2 shown in Fig. (3.16). Before adjusting the gain the operational amplifier is set to zero by grounding its input to earth and altering VR_S1 (shown in Fig. (3.16)).

All unused inputs on the data gathering unit are grounded to earth.

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