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MODELLING BUILDING HEATING REQUIREMENTS

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ABSTRACT

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This thesis describes the development of a mathematical model for the assessment of building heating requirements. The model has been incorporated into a FORTRAN computer program, ENMAN, which allows the rapid production of tabular and graphical comparisons between actual monthly fuel consumption and calculated requirements.

The program was developed for use in a local authority where there was a requirement to monitor the consumption of its building stock which ranges from residential homes to libraries and schools. The ENMAN computer program is used to spotlight any excessive fuel consumption or gradual deterioration in performance.

The principal objective has been to produce a model of building heat requirements which is more sensitive to the effects of occupancy, thermal heat capacity and solar gain than simple thermal models without being unduly complex. This approach was adopted because the large number and range of local authority buildings indicated a requirement for a model which was sensitive to different types of construction and occupancy but which did not require large amounts of input data to describe each building.

The first and second chapters of this thesis form an introduction and also describe the implementation of two other computer programs, ENGY and ICON,which complement ENMAN by allowing an assessment of the thermal environment of buildings and the risk of interstitial condensation.

The third and fourth chapters describe the development of the mathematical model of building heating requirements and its implementation as the computer program ENMAN.

Examples of the use of ENMAN are illustrated and discussed in Chapter 5 . The final chapter concludes by assessing the performance of the ENMAN system and looks at the possibility of future enhancements.

ACKNOWLEDGEMENTS

I am grateful to my two supervisors, Dr. G.G. Rodgers and Dr. A.T. Howarth, for all their advice and encouragement during my period of study.

I would also like to thank Messrs. B.J. Johnson and D. Lawrence of the Programme and Energy Control Unit Sheffield M.D.C. for their practical assistance during the analysis of local authority buildings and Mr. S.C. Herring of the Department of Design and Building Services for his advice on architectural matters.

CONTENTS

1.1 THE HISTORY AND FUNCTION OF ENERGY MANAGEMENT

In recent years the need to conserve energy has become a major issue in society. The traditional fuels are no longer seen as an infinite resource and, since the oil crisis of 1973, the escalating price of the primary fuels has caused the cost of energy to become a significant proportion of the industrial, commercial and domestic budget.

In industry and commerce, where the inefficient use of energy can have a very detrimental effect on company profitability, energy management is taken very seriously. To quote the Department of Energy (1), 'In general, every £10,000 saved in industrial energy costs will yield an extra £10,000 in pre-tax profits. And for the average British firm to achieve a similar increase in profits from output alone would require a rise in sales of at least £120,000. '. It is for this reason that 'Energy Managers' are often to be found at Director level in larger companies.

In Local Government, proper control of energy consumption in council buildings, schools, libraries, sports centres and residential care homes can provide an excellent means of saving money without having to make any cuts in services to the public.

In Great Britain, Central Government has produced many initiatives aimed at the reduction of the nation's energy consumption. Shortly after the 1973 energy crisis the 'Save It' campaign was launched by the Department of Energy, this promoted the efficient use of energy in both the domestic and business sectors. Grants became available for such measures as loft insulation in domestic dwellings. More recently the 'Energy Efficiency Office' has been set up with regional offices coordinating grants throughout the country. Publications such as the Fuel Efficiency Booklets (2), Energy Trends (3), and Energy

Management (4) have given plentiful advice and data on the subject of energy management and have promoted nationwide debate of energy management issues. The current 'HEAT' and 'Energy Efficiency Survey' schemes have made government grants available towards the cost of energy audits which help to identify sources of possible energy savings. Both government and EEC grants are available for research into such topics as solar energy and combined heat and power (CHP).

Tight control over the energy consumption of new buildings has been made possible by the introduction of stringent Building Regulations (5) governing the insulation of external fabric. The insulation values stipulated for walls and roofs are now about one third of the values prevalent in the early 'seventies. Architects and Engineers are now very aware of the need to incorporate good energy-saving features in their designs. Awards are given to energy saving buildings, for example the Electricity Council's 'Gold Medallion' awards for domestic house designs.

All these measures have had an encouraging effect on the nation's energy consumption and fuel usage has fallen from 360 million tonnes of coal equivalent in 1972 to 313 million tonnes in 1983 (3). However there is still enormous potential for more savings to be made and the role of energy management is increasing in importance.

'Energy Management' is the broad title covering all aspects of the efficient use of energy in industrial manufacturing processes, the environmental control of buildings and transport. The process of energy management can be broken down into two fundamental stages:

(i) The IDENTIFICATION of areas of inefficient energy use by means of energy audits and performance analyses.

(ii) The IMPLEMENTATION of measures to reduce consumption in these areas e.g. better heating controls and improved insulation.

It is often the first task which is the most difficult to undertake.

Energy Audits and Performance Analysis

The cost of energy to an organisation must first be analysed and broken down into its constituent parts :- space heating, lighting, hot water and other processes. This can often be the first stumbling block because two or more parts may share one measurement device or meter. The breakdown of different energy usages can be illustrated by a 'Sankey' diagram, an example is given in figure 1.1 . An assessment can then be made as to whether the levels of each energy use are acceptable.

Suppose, for example, that a particular organisation is faced with with its latest annual bill of £10,000 for the space heating of its office building. Is this acceptable or not ? Can it be reduced ? Firstly it may be decided to look at the fuel bills for previous years. If these were significantly less then the cause would need to be investigated. An increase in fuel cost could be due to a combination of many factors :-

(i) inflation of fuel prices

(ii) a colder climate than average

(iii) different patterns of operation of the building e.g. longer hours of use

(iv) lost efficiency of the heating plant and distribution system ; perhaps maintenance is overdue.

(v) heating controls not operating efficiently or thermostats incorrectly set

All these possibilities need to be investigated. Fuel inflation could easily be taken into account by measuring consumption in units of energy rather than units of money. It is the fourth and fifth factors which are generally under the control of the energy manager and so to determine whether efficiency has been lost, the energy consumption must be normalised with respect to the remaining two factors: climate and occupancy.

'Degree Days' are often used as a step towards this normalisation with respect to outside temperatures. The theory of degree days is described in Section 3.2 of this thesis. An allowance for weather variation is made by comparing the monthly or yearly energy consumptions per degree day or by plotting a graph of energy consumption versus degree days as shown in figure 1.2 . This comparison can be done on a monthly or yearly basis; 'rogue' consumptions or an upward trend in consumption can be identified and steps taken to correct the operation of the building. Usually a fixed 'base temperature' of 15.5^{o}c is used because degree day figures for this base are regularly made available (4) for all areas of the country. This base temperature does not strictly apply for all situations however and the variation of occupancy cannot be accomodated with a fixed base degree day method.

The analysis described above draws on the past performance of the building to identify changes in a building's energy usage. Unfortunately it is very possible that energy has been used inefficiently throughout the period of historic comparison: the heating system may have been running inefficiently for many years; there may never have been proper thermostatic control of room temperatures; the fabric of the building may be poorly insulated.

A far deeper analysis can be performed by making a mathematical determination of energy requirement taking into account such factors as climate, occupancy, the fabric heat loss of the building, ventilation solar gains and intermittent heating. By using expected or target values for the efficiency of the heating system and internal air temperatures the mathematical calculation produces a target energy consumption for comparison with actual consumption. In this way a much greater insight is given into the true performance of the building and its heating system.

This greater degree of analysis can be very time consuming if carried out manually but with the aid of computers very complex mathematical analyses may be performed . The next section describes how computers are gradually playing an increasing role in energy management.

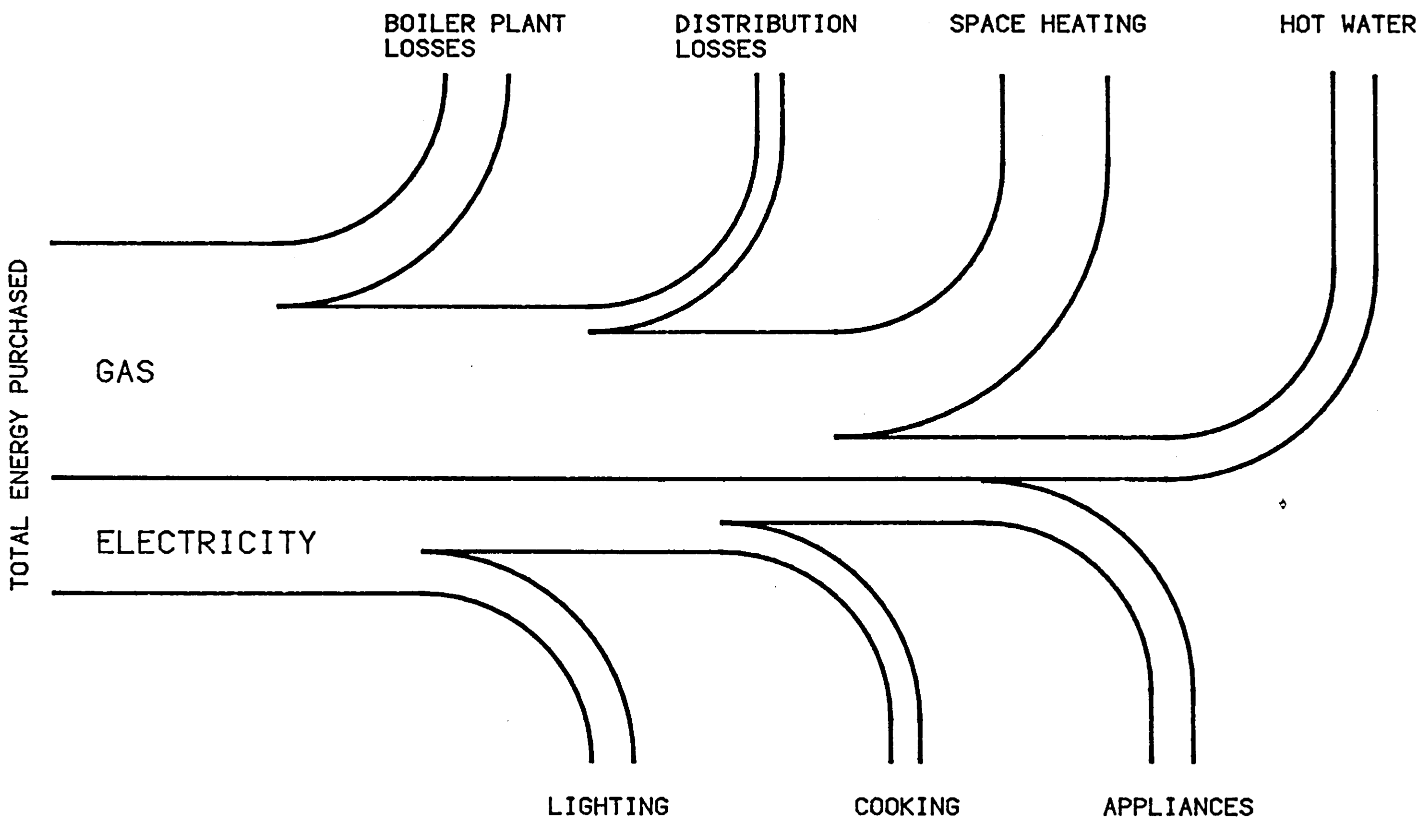


FIG 1.1

A 'Sankey' Diagram For a Typical Building

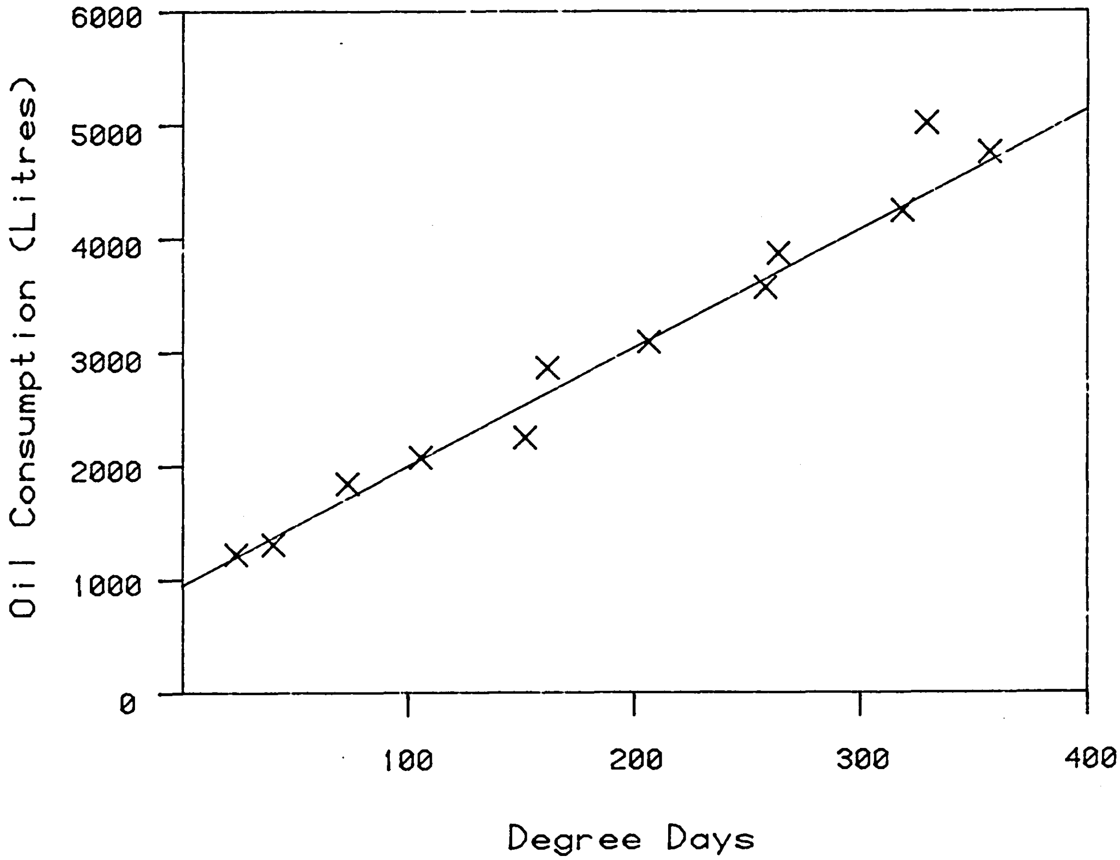


FIGURE 1.2

A Plot of Actual Consumption Versus Degree-Days for a Typical Building

1.2 THE USE OF COMPUTERS IN ENERGY MANAGEMENT

Although the principles of heat flow in buildings have been understood for some years, the mathematical analysis of energy consumption has been limited by the amount of time needed to perform manual calculations. With the aid of computers, complex and repetitive calculations can now be performed extremely rapidly and this has stimulated the development of sophisticated mathematical techniques for determining energy requirement.

For example, the rapid calculation of solar heat gains is now possible using computer programs such as SUN3 , AVDY and OVDY (6) developed at Sheffield University. A program called ENGY (7), also developed at Sheffield, incorporates the calculation of solar gains in a variable base degree-day method for predicting the energy consumption of buildings.

The RIBA (8) have developed a suite of programs for the TI59 programmable pocket calculator, these use degree-days to estimate fuel consumption and also make use of the Admittance Method (9) for calculating peak summertime temperatures in buildings. The CIBS publish a series of algorithms (10) which allow the purchaser to construct his own computer programs using recommended theory.

The Degree-Day and other simple calculation methods assume that 'steady state' conditions prevail within a building ; it is assumed that internal temperatures are constant and that heat flow out of the structure of the building is unidirectional. The solution of the differential equations of non-steady state and two and three-dimensional heat flow has become possible using 'finite difference' and 'finite element' techniques. These techniques can only realistically be undertaken on a computer.

ESP (Environmental Systems Performance) (11) is a computer program developed by the ABACUS unit at the University of Strathclyde. The program uses finite differences to analyse the energy demand of buildings along with heating and cooling plant performance. TAS^{O} (12) developed at Cranfield Institute of Technology uses the 'response factor' method to predict plant load and heating requirement as well as determining humidity levels and condensation risk. Another example of a non-steady state or 'dynamic' analysis is the THERM program developed by British Gas (13).

All of these latter three programs allow the user to feed in details of his buildings and local climate and produce a prediction of each building's performance to compare with its actual performance. Alternatively the programs may be used to investigate new designs or retrofit upgrades to existing buildings. Because calculations are carried out on an hourly basis all the programs are capable of determinining daily internal temperature and plant load profiles, a task which cannot be reliably performed by a steady state analysis. In this way decisions about the implementation of energy saving measures can be made with a greater degree of confidence. Jones (14) explains how the program TAS^{O} was used to analyse different energy saving proposals and shows how the dynamic model in TAS^{O} could produce quite different conclusions to the Degree-Day method in some cases.

Most of the programs available for energy analysis are termed 'interactive'. This means that the order of execution of the various sub-programs which make up the computer program is not fixed but can be dictated by the user during the programs execution. For example, a user may describe a building to the program and produce an energy analysis, he can then go back and change a particular aspect of the building and produce another analysis without having to restart from scratch.

Hardware

In general terms three basic items of equipment or 'hardware' are needed to run an interactive computer program :-

(i) A terminal comprising a keyboard for entering commands and information, and a monitor for displaying the information typed in and for displaying the results of calculations. If the terminal has a graphics capability then it is possible to show the results graphically and to use sophisticated menu systems allowing easy movement between different parts of the program.

(ii) A processor is linked to the terminal and carries out the instructions and calculations contained in the computer program. In its basic form the processor is just a set of many thousands of electrical switches.

(iii) A storage device such as a magnetic disk or tape which is accessed by the magnetic head on a disk or tape drive. The programs themselves and data such as climatic information are stored on these devices. It is also probable that, once a building has been described to the computer,its details will need to be retained for later reference or further analysis.

To give an idea of the rapid progress of computer technology, a computer system used to run a typical dynamic thermal analysis program would have consisted, in the 'sixties or early 'seventies, of a terminal or teletype device linked to a mainframe computer. The cost of such equipment could easily exceed £1 million. In the late 'seventies powerful minicomputers arrived from manufacturers such as DEC and PRIME costing from about £50,000. Currently desktop computers are available which incorporate terminal, processor and disk drive in one unit with sufficient computing power to run complex dynamic programs for less than £20,000. For example, the TAS° program is now available on the APPOLLO range of desktop, networkable computers whose prices start at £13,000. Less complex programs such as those incorporating degree-day models can be run on small microcomputers costing from £100. ENGY is currently being written to run on a BBC microcomputer and disk drive costing about £800.

In this way a computer can be a very cost-effective tool for energy analysis and performance monitoring, and of course,if a computer is purchased it does not have to be used for the sole purpose of energy anlysis, it could also handle the company payroll.

2.1 ENERGY MANAGEMENT IN SHEFFIELD CITY COUNCIL

Sheffield, with a population of some 540,000, is now the fourth largest city in England. Sheffield Metropolitan District Council is directly responsible for the energy management of some 270 schools, 5 Colleges of Further Education, the Polytechnic, 100 residential care homes, 21 sports centres and swimming pools as well as libraries, park buildings, Works Department depots and of course the Town Hall buildings themselves. The total fuel bill for these buildings in 1983/4 was just over £13 million or approximately 7% of the Council's total budget. There are also over 92,000 council homes for which the Authority is responsible in terms of maintenance and modernisation. Such work often involves the provision of new heating systems and additional insulation to combat problems of large fuel bills, condensation and mould growth.

There are, at present, eight full time staff employed in the Council's 'Energy Control' section who are responsible for monitoring the energy usage of Local Authority controlled buildings. Their main responsibilities include :

(i) Keeping records of meter readings and fuel bills for each building.

(ii) Coordinating the maintenance of heating plant and control systems.

(iii) The installation of improved heating controls such as zone controls and optimum start controllers.

(iv) The briefing of Architects and Engineers in the Department of Design & Building Services when design work is required for major heating and insulation schemes.

Examples of successful energy conservation projects initiated by the Energy Control Section include the following :

(i) Westfield and Jordanthorpe Schools : these two schools were built in the 1960's and their external fabric consists of very large areas of glass together with lightweight, poorly insulated panels. Consequently heat losses were considered substantial in winter, but in summer the overheating through excessive solar gain would often become unbearable. On many occasions, rooms facing the sun were overheating while the heating system had to be used to keep rooms on the opposite facade warm. Without zonal control of the heating system it was not possible to heat one side of the building without heating the opposite side,therefore energy was being wasted.

Nearly 50% of the glazing area and all the existing panels, which were in a poor state of repair anyway, have been replaced by well insulated panels. The environment inside each building has been considerably stabilised; staff have expressed satisfaction with their improved environment; fuel bills have dropped and the buildings have had a welcome facelift.

(ii) Acoustically operated lighting has been installed in a number of buildings where lighting use has been excessive. Lights are automatically switched off if no sound is detected for more than fifteen minutes. This has produced considerable savings because lights were often left on during periods of absence.

(iii) A scheme is currently in progress to convert boilers in the Stannington College / Myer's Grove School complex from oil to gas in conjunction with insulation measures such as panel replacement and roof insulation. Savings are expected to be in the region of £50,000 p.a.

(iv) An experimental project is underway monitoring the effects of energy conservation measures on the fuel bills and environmental conditions of inter-war housing. Four houses have been insulated to a very high standard and four of the latest gas and electric heating systems have been installed. These houses are being monitored alongside two other control houses which have had only standard modernisation work carried out. Initial results have been encouraging, showing that fuel bills have been reduced while internal temperatures have been improved . Condensation and mould growth problems appear to have been eliminated.

(v) Heat recovery ventilation systems have been installed in a number of swimming pools. Both latent and sensible heat has been recovered from the exhaust air : this heat would previously have been completely lost. Because of the very high ventilation rates needed to eliminate condensation in swimming pools the savings have been substantial.

The two computer programs ENGY and ENMAN , which are described in this thesis, played a major part in the determination of optimum insulation measures and the assessment of energy savings for the Stannington College Campus and the Low Energy Housing project ((iii) and (iv) above). The Westfield / Jordanthorpe project was carried out before ENGY or ENMAN were available , only manual calculations could be used to assess the benefits of insulation.

2.2 MOTIVATION FOR THE WORK REPORTED IN THIS THESIS

Background

The Local Authority's initial interest in the use of computers for energy calculations followed a seminar on Energy Conservation arranged by Mr. Bernard Johnson of the Council's Energy Control Section. There had been increasing concern amongst Council members and officers about the problems of condensation and mould growth in council homes. They realised that it was often not sufficient to simply advise tenants to open windows more often and turn up their heating systems because of the effect this had on heating bills. As part of the seminar Dr. Glinn Rodgers of the Department of Building Science at Sheffield University showed how the computer program ENGY could be used to make a far deeper technical analysis of heating and condensation problems by balancing the effects of ventilation, heating and insulation.

Following the seminar, an initial study of heating problems at Broomhall Flats, one of Sheffield's system-built housing developments, was undertaken using ENGY on the University's PRIME 750 minicomputer. Various options for insulating the flats were explored and the results were presented to the Council's Housing Committee. At this stage it was realised that ENGY could be of great use to the Authority but, for practical reasons the program would need to be mounted on the Authority's ICL 2900 mainframe computer. Because of the differences between the operating systems of the ICL and PRIME machines and also the differences between ICL FORTRAN and the PRIME version of the FORTRAN programming language used for ENGY , it was obvious that the conversion could take several months and would require an experienced FORTRAN programmer. At the same time it was realised that the calculation of energy consumption made by ENGY could be modified to permit the comparison of actual fuel consumption of local authority controlled buildings with a computer based calculation. This would be of great use to the Authority's Energy Control Section in establishing a priority list of buildings such as schools and old peoples' homes which may require energy conservation work such as boiler maintenance, improved heating controls and insulation.

It was thus decided to set up a Research Project funded by the Local Authority and under Dr. Rodger's supervision. There were two basic aims :-

(i) To perform the conversion of ENGY to run on the Council's mainframe computer.

(ii) To develop a modified mathematical model and implement a new computer program , ENMAN , for analysing the energy consumption on a month by month basis using monthly reports of local climatic data rather than the 30 year averages used by ENGY.

During the first stage of work another computer program, ICON , was written as an aid to the investigation of interstitial condensation problems: this was largely carried out as a familiarisation exercise with the use of computer graphics but the program has seen extensive use by council architects. The three programs ENGY, ICON and ENMAN are briefly introduced below:-

ENGY

The first three months of the research project were spent in the conversion of ENGY. Although the program was written in the FORTRAN language the ICL 2900 uses a slightly different form of the language to the PRIME version. Without going into great detail, most of the problems were concerned with the differences in the way character variables are handled. The VME/B operating system of the ICL machine is also very different to the PRIMOS system of the PRIME 750 and many sections of the program had to be re-written to accomodate these differences. In particular the handling of data files is very different.

Once the ICL version of ENGY was working at the Town Hall its calculations were checked by comparison with the University's PRIME version, only then was the program considered to be fully implemented.

The first exercise for which the new version of ENGY was used was an investigation into mould growth problems at Hawley Street Flats, a solid-walled inner city tenement building constructed at the turn of the century. The tenants were experiencing damp conditions and very high heating bills which they could not afford. ENGY was used to investigate the effects of such measures as dry-lining with thermal insulation and double-glazing. Examples of the output from ENGY are shown in Appendix I which contains **the actual** report based on the ENGY study ; the recommendations of this report have now been implemented as part of a complete refurbishment of the flats.

ICON

The COND module of ENGY can be used to predict the liklihood of surface condensation on external walls and windows. Another problem however is that of 'interstitial condensation' which can occur between the inside and outside surfaces of a structure. There have been many problems of interstitial condensation, particularly in flat roofs, which result from water vapour permeating to cold areas within the structure of buildings. The FORTRAN program ICON was written to investigate these problems. The theory behind the program is derived from BS 5250 (15) and also involves the use of a polynomial curve fitted to to the CIBS Psychrometric Chart which allows a dewpoint temperature to be determined given the moisture content of the air. The program uses a similar menu system to that of ENGY. Examples of output from the program are given in Figures 2.1 and 2.2 .

<u>ENMAN</u>

The development of ENMAN forms the major part of the project reported in this thesis.

As described in Section 2.1 , Sheffield City Council is directly responsible for the energy management of some 400 buildings and, with the Energy Control Section numbering just some seven staff, the monitoring of fuel consumption has been very limited. The aim of the ENMAN project has been to development of a mathematical model which enables the calculation of 'guidelines' based on each building's construction, its usage and the local climate. The model is implemented as a computer program capable of handling calculations for all the Local Authority controlled buildings whose performance can be monitored by comparison of actual consumption with the calculated guidelines.

It was recognised that other local authorities had carried out broadly similar work. For instance : Essex County Council (16) have used the TAS^{O} program to carry out extensive analysis of the consumption of school buildings and also for the assessment of new designs ; Bradford City Council in conjunction with Bradford University (17) have developed a simpler system capable of handling many hundreds of buildings. Although TAS° is an excellent tool for performing detailed analyses of individual buildings, the amount of detailed information required for each building effectively precludes its use for a large number of buildings. For a straightforward comparison **of seasonal heat requirements, as opposed** to daily plant load profiles , a simpler approach is more practical. The system used at Bradford aims to achieve a comparison between consumptions per degree day on a historical basis and to compare consumptions per unit floor area and per occupant between different buildings. However, the system appears not to take account of the variation of building construction and occupancy. It is , therefore, essentially a computer implementation of year by year and month by month degree day comparisons described in Section 1.1 . The drawbacks of this type of analysis are described in Sections 1.1 and 3.2 .

The ENMAN system aims to fall between the work of these two Local Authorities. Important factors such as the fabric construction and occupancy of a building are taken into account but the amount of input information is kept at a level which reflects the number of buildings to be analysed. Although the absolute accuracy of ENMAN program is limited by the assumptions made by the the mathematical model it will be shown that improved accuracy which could, possibly, be achieved using a more complex model is insignificant compared to the inherent unreliability in the specification of important input parameters such as U-values and occupancy patterns.

The remainder of this thesis is concerned with the development, implementaion and use of the ENMAN system. The development of the mathematical model is described in Chapter 3 ; the implementation of this model into a FORTRAN computer program is described in

Chapter 4. Examples of the output from the program are illustrated and discussed in Chapter 5. Chapter 6 concludes by reflecting on the usefulness of the program and the possibility of future modifications.

DRY LINED SOLID WALL

U-VALUE = 0.54 W/M2K

INTERNAL AIR TEMP. 20.0DEGC   INTERNAL RH 60.0%
EXTERNAL AIR TEMP. 0.0DEGC   EXTERNAL RH 95.0%

LOCATION	STRUCTURAL TEMP (DEGC)	MOISTURE CONTENT (KG/KG)	DEW POINT TEMP (DEGC)
INT AIR	20.0	0.0089	12.1
INTERFACE 1	18.7	0.0089	12.1
INTERFACE 2	18.1	0.0088	12.0
INTERFACE 3	18.1	0.0058	3.3
INTERFACE 4	3.4	0.0048	2.7
INTERFACE 5	0.5	0.0036	-0.7
EXT AIR	0.0	0.0036	-0.7

	MATERIAL NAME	THICK -NESS	K-VAL	THERMAL R'STANCE	VAPOUR R'STIVITY	VAPOUR R'STANCE
1	PLASTER	9.5	0.160	0.06	60.0	0.6
2	VAP.CHECK	---	---	---	---	55.0
3	POLYURETHANE	30.0	0.022	1.36	120.0	3.6
4	BRICK	225.0	0.850	0.26	75.0	18.0

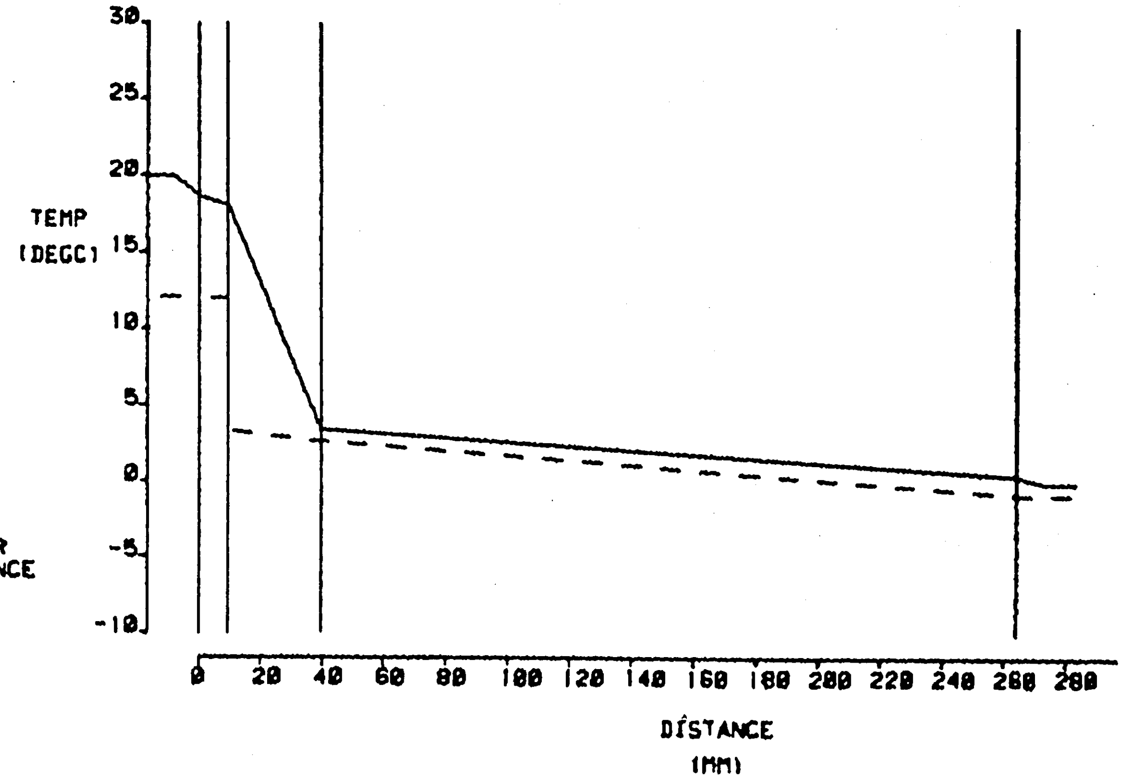


FIGURE 2.1

Example of the Output from Program ICON

CAVITY WALL

U-VALUE = 1.34 W/M2K

INTERNAL AIR TEMP. 20.0DEGC   INTERNAL RH 60.0%
EXTERNAL AIR TEMP. 0.0DEGC   EXTERNAL RH 95.0%

LOCATION	STRUCTURAL (DEGC)	MOISTURE (KG/KG)	DEW POINT (DEGC)
INT AIR	20.0	0.0089	12.1
INTERFACE 1	16.8	0.0089	12.1
INTERFACE 2	16.1	0.0086	11.6
INTERFACE 3	9.3	0.0062	6.4
INTERFACE 4	4.5	0.0062	6.4
INTERFACE 5	1.3	0.0036	-0.7
EXT AIR	0.0	0.0036	-0.7

MATERIAL NAME	THICK -NESS	K-VAL	THERMAL R'STANCE	VAPOUR R'STIVITY	VAPOUR R'STANCE
1 PLASTER	12.0	0.460	0.03	60.0	0.7
2 BLOCKWORK	100.0	0.400	0.25	70.0	7.0
3 AIRSPACE	75.0	---	0.18	---	0
4 BRICK	100.0	0.850	0.12	75.0	7.5

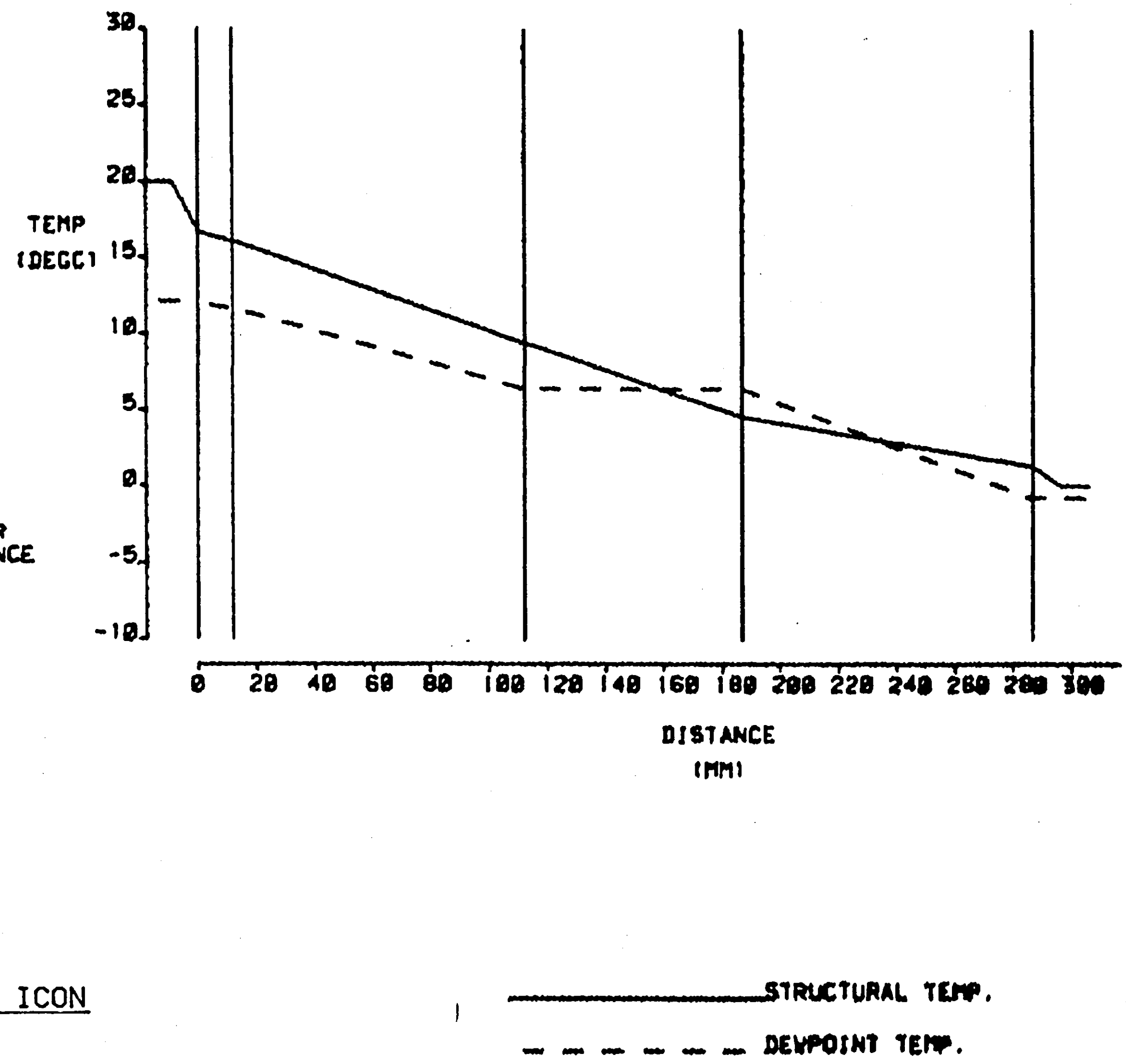


FIGURE 2.2

Example of the Output from Program ICON

CHAPTER 3

DEVELOPMENT OF THE MATHEMATICAL MODEL OF BUILDING HEAT REQUIREMENT

3.1 INTRODUCTION

This chapter describes the development of the mathematical model which provides the basis of the ENMAN computer program. The model allows the monthly prediction of a building's energy requirement for comparison with actual energy usage.

The aim throughout the ENMAN project has been to strike a compromise between the amount of information needed to describe a building for analysis by the model and the accuracy of the predictions which are produced.

As discussed in Chapter 2, the majority of mathematical models currently used as an aid to energy management tend to lie at one of the following two extremes :

(i) A simple degree day method using a fixed base temperature, usually 15.5°c. Predictions of space heating consumption are made by multiplying the degree day total by the total heat conductance of the building. The only information required by such a method are the areas and U-values of the external fabric and the enclosed volume of the building together with degree day totals which are published monthly by the Department of Energy (4)

(ii) A full dynamic thermal model where thermal capacity, intermittent heating, and zoning of the building are all taken into account. Such models require the description of the connectivity between different zones of the building and details of internal as well as external fabric. Occupancy patterns have to be described in detail for each zone. Hourly climatic data is usually required.

The model described in this chapter aims to build on the Degree-Day method by taking some account of important factors such as intermittent heating, thermal capacity, solar gains and occupancy patterns. However, the information necessary to describe a building is kept to a reasonable limit. With the ultimate aim of having several hundred buildings processed by ENMAN this approach was considered to be the most appropriate.

The theory of degree-days is described in Section 3.2 . Two major assumptions of a simple degree-day method are that temperatures within a building are constant with time and that the thermal capacity of the building can be ignored. Section 3.3 explains why an adapted degree-day method can still be valid for an intermittent heating regime with some account taken of thermal capacity.

Section 3.4 describes how the occupancy of a building can affect its energy requirement and shows how the major effects of different styles of occupancy can be accomodated without the necessity of providing vast quantities of information about occupancy patterns.

Section 3.5 describes how a solar gain prediction method developed by the Department of Building Science at Sheffield University (18) has been adapted for use by ENMAN.

The calculation procedure embodied in the chosen mathematical model is summarised in Section 3.6.

A comparison between different calculation methods is made in Section 3.7 . The significance of the discrepancies between the predictions made by these models is discussed.

3.2 DEGREE - DAYS AND CONTINUOUS HEATING

The use of 'degree-days' originated in the American Gas Industry; their use was first introduced in Britain by Dufton (19) in 1934. Further work by McVicker (20) in 1946 and Billington (21) in 1966 established the Degree-Day method as one of the standard procedures for determining the effect of climate on the energy consumption of buildings. The use of the method has since been recommended by the Department of Energy (2).

The main assumptions of the Degree-Day method are that steady-state conditions prevail within the building and that the thermal capacity of the structure can be ignored. Thus at any instant of time, the heat flow, Q (W), out of the structure will be proportional to the instantaneous difference between the inside and outside air temperatures t_i and t_o (^oc) :-

$$Q = (q_f + q_v) (t_i - t_o) \qquad 3.2.1$$

where, ($q_f + q_v$) is the total heat conductance of the building ($W/^oc$) consisting of the fabric conductance, q_f, of the external envelope of the building and the ventilation conductance, q_v, which allows for heat lost by the ventilation of warm inside air to the outside. Both q_f and q_v are assumed to be constant.

With 24 hour continuous heating we may assume, for a fully controlled heating plant, that t_i is approximately constant. Figure 3.1 shows the typical variation of t_i and t_o over a 24 hour period. The heat requirement over the period will be proportional to the shaded area in the figure. This heat requirement will not have to be provided completely by the heating plant ; there will be heat gains from the sun, artificial lighting, human body heat and other items. As long as these heat gains do not cause overheating, where energy could be lost from the system by the occupants opening windows for example, their sum can be assumed completely useful. They are represented by the area ABEF in figure 3.1. The heat requirement from the plant will now be proportional to the area enclosed by EFCD. The line EF corresponds to a fictitious temperature , t_b ($^\circ$c) known as the degree-day 'base temperature' . In reality t_b is not constant because more heat gains are likely to occur during the daytime; however this would only be important if the outside temperature exceeded the base temperature at some time during the day. In Britain's climate this would normally only occur between May and September and should not affect the more important winter predictions. The problem of t_o exceeding t_b is, to some extent, dealt with by the use of the British Gas method of estimating degree-days which is described below; this discussion is also expanded in Section 3.3.

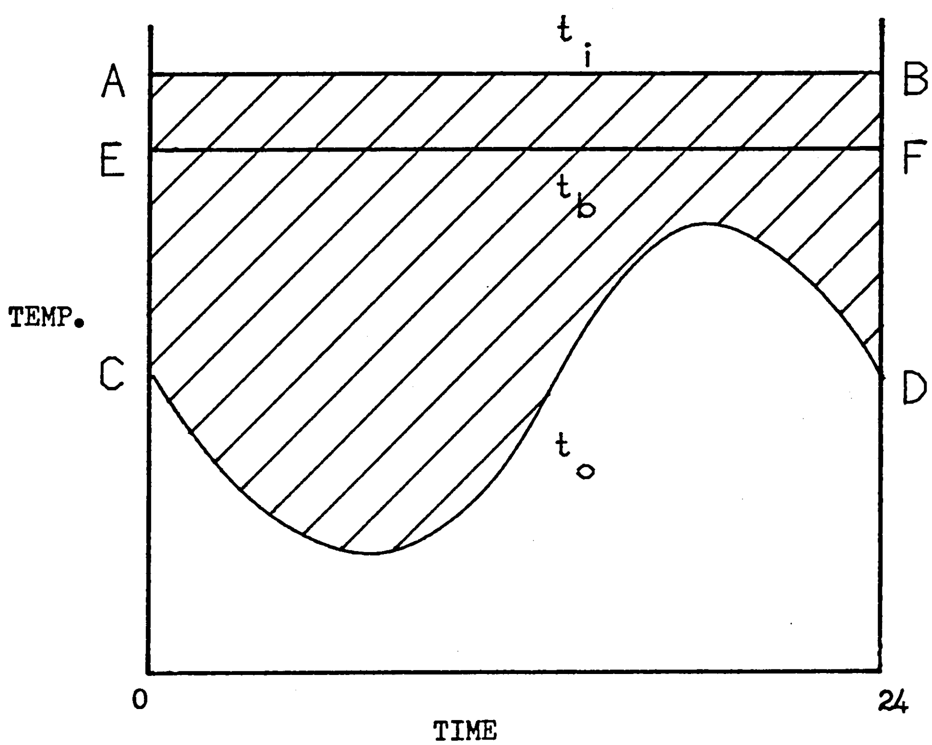


FIGURE 3.1

Variation of Internal and External Air Temperature Over 24 Hours

Further analysis of equation 3.2.1 allows t_b and the seasonal heating plant requirements to be determined :-

Using time intervals of one day, the seasonal heat balance may be expressed as,

$$H = \frac{24}{1000} (q_f + q_v) \sum_{k=1}^{N_s} (\bar{t}_{ik} - \bar{t}_{ok}) \qquad 3.2.2$$

where, H is the total heat required (kWh) to maintain an average inside temperature of $\bar{t}_i$ (^{o}c)

N_s is the number of days in the heating season.

In the case of continuous heating, $\bar{t}_{ik} = t_d$, the internal design temperature. If H_p is the heat supplied by the heating plant and H_w the incidental heat gains (kWh) then,

$$H_p + H_w = \frac{24}{1000} (q_f + q_v) \sum_{k=1}^{N_s} (t_d - \bar{t}_{ok}) \qquad 3.2.3$$

which can be rewritten,

$$H_p = \frac{24}{1000} (q_f + q_v) \sum_{k=1}^{N_s} (t_d - \bar{t}_{ok} - t) \qquad 3.2.4$$

where, $t = \dfrac{1000 H_w}{24 N_s (q_f + q_v)}$,the temperature reduction caused by incidental heat gains (^{o}c)

The expression $\sum_{k=1}^{N_s} (t_d - \bar{t}_{ok} - t)$ (^{o}c day) is the number of degree days , $D(t_b)$, below the base temperature $t_b = t_d - t$; an alternative form of equation 3.2.4 is thus,

$$H_p = \frac{24}{1000} (q_f + q_v) D(t_b) \qquad 3.2.5$$

and,

$$t_b = t_d - \frac{1000\ H_w}{24\ N_s\ (\ q_f + q_v\ )} \qquad 3.2.6$$

The Department of Energy considers an internal air temperature of 18.3 °c to be comfortable for normal living purposes and observations have shown that, in maintaining this temperature, the heating requirement more closely relates to the extent by which the outside air temperature falls below 15.5 °c . This implies that a value for t of 2.8 °c is used to take account of the effects of incidental heat gains. The DoE regularly publish (4) degree-days to a base temperature of 15.5 °c. For many buildings however this figure is unrealistic : the correct value for t_b should take account of the actual level of incidental heat gains and the heat conductance of the building using equation 3.2.6 .

Models which take account of these factors are termed 'variable base' degree-day methods , an example of which is the model embodied in the computer program ENGY (7).

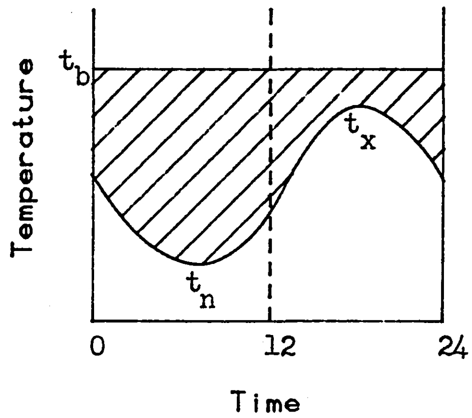
The value of $D(t_b)$ is found by summing the daily values of the area EFCD in figure 3.1. To calculate degree-days in practice, several methods are available. Because the weather data supplied by our weather station in Sheffield contains only maximum and minimum daily air temperatures it was decided to adopt the British Gas method (22). An advantage of their method is that degree-days for heating and cooling are totalled separately so that,on a day where the base temperature lies between the maximum and minimum outside temperatures,a correct figure for the night-time heat requirement is obtained ; the assumption being that surplus heat gains during the day-time cannot be used to compensate for night-time requirements.

Illustrated in figure 3.2 are the four different temperature profile cases together with the empirical formulae used for estimating degree-days.

Discussion

Nearly all the simple models for calculating heating plant requirements are based on the fundamental equation 2.2.1. Uglow (23) describes one such model. Hitchin and Hyde (24) have compared several models including the Degree-Day Method ; their conclusion was that the Degree-Day Method is probably the most complete of the simple models.

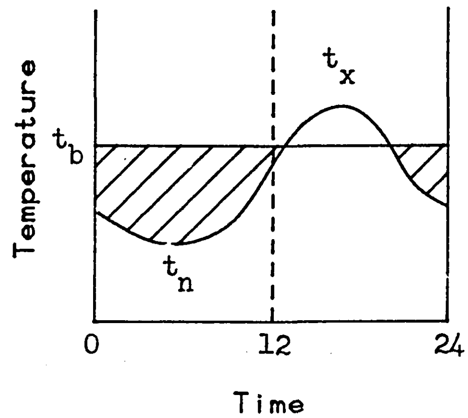
The main problem with the method lies in its use for intermittently heated buildings wher t_i is not constant. The following section shows how this problem may be overcome by calculating the average internal air temperature , $\bar{t}_i$, and modifying the base temperature accordingly.



CASE 1

$t_x < t_b$

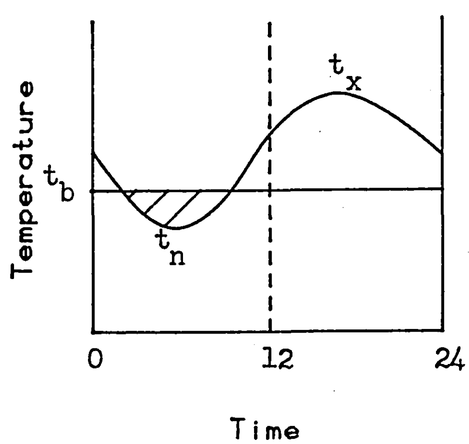
$$D(t_b) = t_b - \frac{(t_x + t_n)}{2}$$



CASE 2

$(t_x - t_b) < (t_b - t_n)$

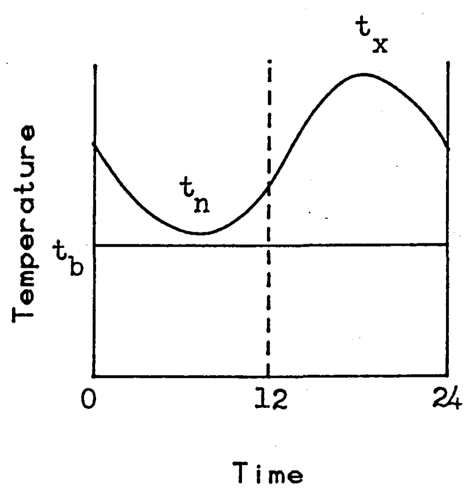
$$D(t_b) = \frac{(t_b - t_n)}{2} - \frac{(t_x - t_b)}{4}$$



CASE 3

$(t_x - t_b) > (t_b - t_n)$

$$D(t_b) = \frac{(t_b - t_n)}{4}$$



CASE 4

$t_n > t_b$

$$D(t_b) = 0$$

FIGURE 3.2

EMPIRICAL EQUATIONS FOR THE ESTIMATION OF DEGREE-DAYS

3.3 THERMAL CAPACITY AND INTERMITTENT HEATING

Heat Storage

Every building structure has a capacity to store heat. It is for this reason that buildings are observed to have a 'thermal inertia' whereby internal temperatures do not instantly respond to changes in heat input.

In a building of large thermal capacity e.g. a heavy masonry structure, the effects of thermal inertia can be substantial. After a long shutdown it can take several hours of preheating for the heating system to bring internal temperatures up to a comfortable level, conversely the building will cool down very slowly after the heating is switched off. On hot sunny days the environment inside such buildings can remain comfortably cool because the structure has a thermal averaging effect which damps out peaks of solar heat gain.

Buildings of low thermal capacity built of lightweight materials, e.g. timber frame constructions, respond more quickly to heat inputs. Such buildings require little preheat time but are often subject to overheating during periods of high solar gain. Internal temperatures can fall very rapidly when the heating system is switched off and additional frost protection may be required in buildings that are intermittently heated during the winter.

A more correct heat balance than that of Section 3.2 includes consideration of heat storage:-

HEAT INPUT	=	HEAT LOST TO OUTSIDE	+	HEAT STORED IN FABRIC

At any instant of time the quantity of heat absorbed by the fabric may be positive or negative depending on the difference between the temperatures of the fabric and internal environment.

Over short time periods such as one day the change in heat stored can be significant compared to the total heat lost. However, as discussed by Hitchin and Hyde (24), over longer periods such as a month the change in the mean temperature of a building structure between the beginning and end of the period is likely to be a few degrees at most. The difference in energy stored in the structure is consequently two or three orders of magnitude lower than the total heat requirements. For these reasons the Degree Day method can be reliable for calculating energy requirements over periods of a month or more but the method should not be used for daily or weekly calculations.

Variation of Inside Air Temperature

With continuous heating it could reasonably be assumed that the air temperature within a building would be constant with time. In practice there would be small variations of temperature within the set limits of each thermostat but variations of short duration should not have a marked effect on predicted energy use.

When a building is intermittently heated, inside temperatures are allowed to drop when the heating is turned off. A building of high thermal capacity will store sufficient heat during the heating period to keep inside temperatures well above outside if the 'off' period is not of long duration. Temperature variations of less than four or five degrees between the 'on' and 'off' periods are common (25). Peach (26) recognised that, in addition, most incidental heat gains are likely to occur during the heating period when occupants are present and solar energy is being received. As illustrated in Figure 3.3, the effect is that the fictitious base temperature used by the Degree Day method is even less variable than the inside air temperature. Therefore, the Degree Day method could still be expected to hold for buildings of heavyweight construction and the degree day base temperature could be determined in a similar manner to that described in Section 3.2.

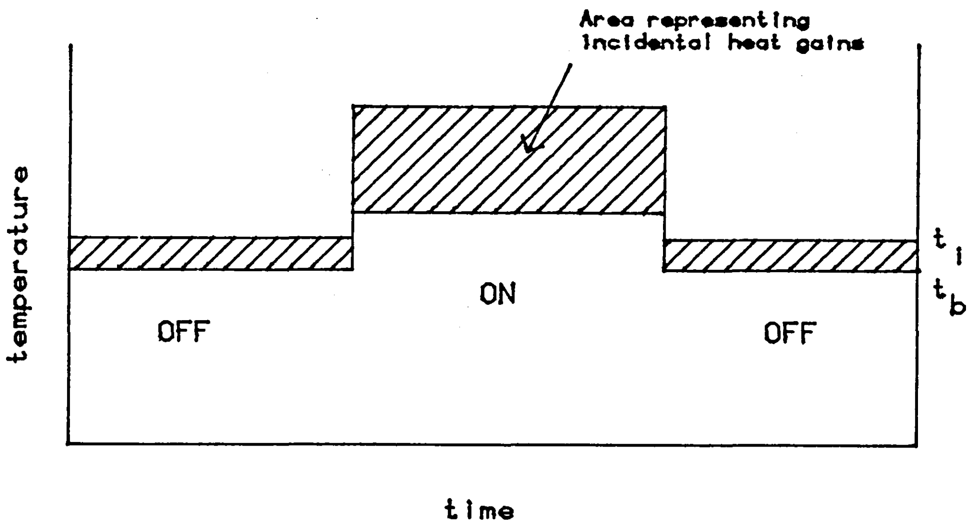


FIGURE 3.3

Variation of Internal Temperature for Intermittent Heating

However, in order to determine a more representative base temperature , particularly for buildings of low and medium thermal capacity , it is necessary to more precisely establish the variation of internal temperatures.

The extent to which the internal temperature will fall during the 'off' period and its rate of decrease will be affected by three factors :-

(i) the difference between inside and outside air temperatures

(ii) the length of time for which the heating is left off

(iii) the thermal capacity of the building related to its heat conductance

In order to take account of these factors the concept of 'Admittances' has been incorporated into the degree day model.

The Admittance Procedure

The theory of 'admittances' was originally developed to investigate the overheating of buildings in summertime. The need for this analysis arose from changes in construction practice which had caused many schools and offices to be built with large areas of glazing and a thermally lightweight construction.

Loudon and Danter (27, 28, 29) developed a method of determining the thermal response of buildings to cyclic energy inputs such as solar heat gain. This work was further developed by Millbank and Harrington-Lynn (30, 31) and forms the basis of the admittance procedure described in the CIBS Guide Section A5 : 'Thermal Response of Buildings' (9).

The fundamental theory of the admittance procedure is that any periodic change in heat input or temperature can be represented by an average condition and a series of sinusoidal changes at increasing frequency - a 'Fourier Analysis'. The admittance method ignores all frequencies other than the fundamental 24 hour cycle such that two equations of heat flow now apply :-

$$\bar{Q} = (q_f + q_v) (\bar{t}_i - \bar{t}_o) \qquad \text{AVERAGE} \qquad 3.3.1$$

$$\tilde{Q}_\theta = (q_y + q_v) \tilde{t}_{i\theta} \qquad \text{SWING} \qquad 3.3.2$$

where, $q_y = \Sigma AY$ the sum of the products of area and admittance for all internal and external surfaces in the building (W/^{o}C)

Y is the admittance factor calculated for each suface and is the amount of energy (W/m^2 ^{o}C) entering the surface for each degree of temperature swing.

$\bar{t}_i$, $\bar{t}_o$ are the daily means of internal and external air temperature.

$\tilde{Q}_\theta$ (W) and $\tilde{t}_{i\theta}$ (^{o}C) are the swings of heat input and internal temperature about their respective mean values $\bar{Q}$ and $\bar{t}_i$ such that at any time θ, $t_{i\theta} = \bar{t}_i + \tilde{t}_{i\theta}$ and $Q_\theta = \bar{Q} + \tilde{Q}_\theta$.

Although accuracy is lost by ignoring frequencies other than the fundamental, Millbank and Harrington-Lynn (30) have shown that the errors incurred are not significant. More complex models do exist which take into account the higher frequencies in the Fourier series : these are the 'Response Factor' models mentioned in Section 1.2 .

At any time θ, the heat balance for a building is now given by :

$$Q_{p\theta} + Q_{w\theta} = \underbrace{(q_f + q_v)(\bar{t}_i - \bar{t}_o)}_{\text{average}} + \underbrace{(q_y + q_v)(t_{i\theta} - \bar{t}_i)}_{\text{swing}} \qquad 3.3.3$$

where, $Q_{p\theta}$ and $Q_{w\theta}$ are the heat inputs (W) from the heating plant and from incidental heat sources.

For intermittently heated buildings the 24 hour cycle is split into the 'ON' and 'OFF' periods.

During the ON or control period $t_{i\theta} = t_d$, the design internal air temperature, thus :

$$Q_{p\theta} + Q_{w\theta} = U' (\bar{t}_i - \bar{t}_o) + Y' (t_d - \bar{t}_i) \qquad 3.3.4$$

where, $U' = (q_f + q_v)$ and $Y' = (q_y + q_v)$

During the OFF period $Q_{p\theta} = 0$ hence,

$$Q_{w\theta} = U' (\bar{t}_i - \bar{t}_o) + Y' (t_{i\theta} - \bar{t}_i) \qquad 3.3.5$$

The preheat period is undefined in the admittance procedure. Summing over 24 hours and noting that , by definition ,

$\sum_{\theta=1}^{24} (t_{i\theta} - \bar{t}_i) = 0$ we have :

$$\sum_{\theta=1}^{24} Q_{w\theta} + \sum_{\theta=k}^{h_p+k} Q_{p\theta} = 24\, U' (\bar{t}_i - \bar{t}_o) \qquad 3.3.6$$

where, h_p is the plant ON time in hours.

Summing over the control period,

$$\sum_{\theta=k}^{h_p+k} Q_{p\theta} = h_p U' \left(\bar{t}_i - \bar{t}_o \right) + h_p Y' \left(t_d - \bar{t}_i \right) - \sum_{\theta=k}^{h_p+k} Q_{w\theta} \qquad 3.3.7$$

Eliminating Q_p between equations 3.3.6 and 3.3.7 yields

$$\sum_{\theta=1}^{24} Q_{w\theta} - \sum_{\theta=k}^{h_p+k} Q_{w\theta} = (24 - h_p)\, U'(\bar{t}_i - \bar{t}_o) - h_p Y'(t_d - \bar{t}_i) \qquad 3.3.8$$

If all the incidental heat gains are assumed to occur during the heating period then $\sum_{\theta=1}^{24} Q_{w\theta} = \sum_{\theta=k}^{h_p+k} Q_{w\theta}$ and equation 3.3.8 may be written,

$$(24 - h_p)\, U' (\bar{t}_i - \bar{t}_o) = h_p\, Y' (t_d - \bar{t}_i) \qquad 3.3.9$$

and some rearranging gives :

$$\bar{t}_i = \frac{(24 - h_p)\, U' \bar{t}_o + h_p\, Y' t_d}{U' (24 - h_p) + h_p\, Y'} \qquad 3.3.10$$

by putting $f_r = \frac{Y'}{U'}$, the total building 'response factor' :

$$\bar{t}_i = \bar{t}_o + \frac{h_p f_r (t_d - \bar{t}_o)}{h_p f_r + (24 - h_p)} \qquad 3.3.11$$

which is the equation given in the CIBS Energy Code (32)

Substitution for $\bar{t}_i$ in equation 3.3.6 now gives,

$$\sum_{\theta=1}^{24} Q_{w\theta} + \sum_{ON} Q_{p\theta} = 24\, U' \frac{h_p f_r (t_d - \bar{t}_o)}{h_p f_r + (24 - h_p)} \qquad 3.3.12$$

or,

$$\sum_{ON} Q_{p\theta} = 24\, U' B \left(t_d - \bar{t}_o - \frac{\sum_{\theta=1}^{24} Q_{w\theta}}{24\, U' B} \right) \qquad 3.3.13$$

$$\text{where,} \quad B = \frac{h_p f_r}{h_p f_r + (24 - h_p)} \quad \text{, the 'intermittency factor'.}$$

If we consider a heating season of N_s days we now have an equation of similar form to equation 3.2.4 in Section 3.2 such that,

$$H_p = \frac{24}{1000} B (q_f + q_v) D(t_b) \qquad 3.3.14$$

where, H_p is the seasonal heat requirement (kWh) from the heating plant and t_b is now given by,

$$t_b = t_d - t / B \qquad 3.3.15$$

A similar derivation to that shown above is given by Moore and Holmes (33). Spooner (34) compared average temperatures calculated from equation 3.3.11 with actual internal temperatures from a carefully monitored house and suggested that there was good agreement.

Time Lags

Due to the capacity of a building's fabric to store heat, there will be a certain time lag between a change in external temperature and the corresponding fluctuation in internal surface temperature. Time lags have been ignored in the above derivation. However, as long as it can be assumed that external conditions one day are more or less like the next then the average outside temperature would be about the same and a summation of degree-days would still be expected to be representative of the heat requirement. On the whole, this is true of Britain's climate and sharp changes of more than a few degrees between one day and the next are uncommon.

Utilisation of Solar Heat Gains

Not all the solar radiation entering through the windows of a building may represent useful heat gain. The thermal averaging effect of the thermal capacity of a building will damp out peaks of solar gain but at times it is still possible that heat gains will exceed the heat losses from the building. At these times there will be a surplus of heat and the building will overheat unless steps are taken to prevent overheating e.g. by air conditioning or incresed natural ventilation.

Owens (35) has proposed the use of utilisation factors whose value depends on the thermal capacity of a building and the ratio of heat gains to heat losses. Uglow (36) also suggests the use of utilisation factors and she gives a range of factors for light, medium and heavyweight buildings for different glazing orientations.

The British Gas method of calculating degree-days already takes some account of the incomplete utilisation of incidental heat gains. Figure 3.3 shows that, when the degree-day base temperature lies between the maximum and minimum outside temperatures, only the shaded proportion of incidental gains are considered useful. In other cases, when the base temperature exceeds the maximum outside temperature,

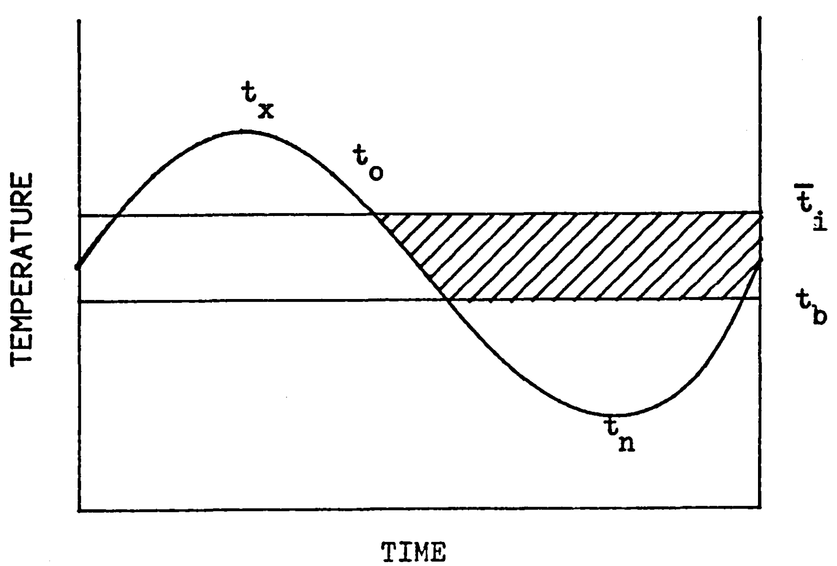


FIGURE 3.4

The variation of temperature over 24 hours for the case $t_n \leq t_b \leq t_x$

all the incidental gains are considered useful but at these times there is unlikely to be surplus heat. Although it is difficult to show that this method makes correct allowance for surplus heat gains it would be wrong to apply the utilisation factors of Uglow or Owens because they have been developed for use in different methods of calculation of heat requirement.

3.4 THE EFFECTS OF OCCUPANCY

Apart from climatic conditions and constructional properties of the building such as external fabric areas, U-values and window arrangement all the parameters affecting the use of energy within a building are dependant upon the lifestyle of its occupants.

Hours of heating, temperature and ventilation standards, incidental heat gains arising from artificial lighting and human body heat are all governed by the type of activities for which a building is being used. Where other utilities such as cooking or hot water are included on the same meter as space heating, the occupants will have a direct effect, residential buildings generally having a much higher requirement per person.

A conventional fixed base degree day calculation of energy requirement would take no account of the variation of these factors from building to building. The only variables considered by such a method are outside air temperature and the total heat conductance of the building expressed in watts per degree centigrade. As a consequence two constructionally identical buildings would be predicted to have the same energy requirement even if one was an old peoples' home while the other was a school. There are several reasons for the energy requirement to be different in reality, for example :

(i) An old peoples' home would probably be heated for 24 hours a day, a school only during the daytime.

(ii) Old people generally require higher temperatures for comfort than school staff or pupils because of their lower rate of activity and body metabolism. The thermostats would therefore be set a few degrees higher than in a school.

(iii) The ventilation rate in a school is likely to be higher because external doors probably have to be opened more frequently during classroom changes etc.

(iv) Non-solar incidental gains would probably be greater in a school because more use is likely to be made of artificial lighting and the density of population is greater causing more gain from body heat. These gains are available to offset the requirement for heating fuel.

(v) Hot water consumption will be more per person in an old peoples' home because bathing and clothes washing usually take place on the premises. This must be balanced against the lower density of occupation so the overall consumption may be less. This consumption is important when fuel consumption for hot water production shares the same meter as space heating, because to make a comparison of predicted fuel consumption with actual consumption would require some estimate of hot water usage.

The aim of the calculation methods described in this thesis is to take some account of these effects without going into extensive detail of occupancy patterns and style. It was considered that,to give an approximate reflection of the effects of occupancy, each building should be classified to its 'type' - school, old peoples' home, office etc. and that the approximate number of occupants be given together with an estimate of the hours of occupation per day and days per week.

A full list of the type classifications used by ENMAN is given in Table 3.1 . The following subsections contain discusion about each of the parameters which are affected by occupancy. and also attempt to justify the choice of values for each 'type' of building.

Temperature and Ventilation Requirements

There are many complex infiltration models which allow the calculation of ventilation rate from a knowledge of crack sizes, frequency of door openings, and wind speed and direction. In the real world however these parameters are difficult to establish. For the purposes of setting energy targets it is not necessary to be concerned with the actual rate of ventilation, but rather with an achievable target. It would be possible to allow only for fresh air requirements, but this would be an unrealistic target to achieve in a real building and such low ventilation rates may give rise to condensation problems.

By using 'design values' in the prediction model any building with an unacceptably high ventilation rate should be spotlighted because the actual energy consumption is likely to be greater than the predicted energy requirement. At the same time, the design value must be an achievable figure for that type of building.

Design values of ventilation rate have, in general, been taken from the CIBS Guide (37). The values given in the Guide are for the sizing of heating plant and therefore relate to the ventilation rate during the plant 'ON' period. The model described in this thesis requires a 24 hour average rate of ventilation so, in the case of intermittently occupied buildings, the Guide values have been reduced. It is difficult to properly justify the level of these reductions but, in the absence of much published material on the subject and in view of the general uncertainty about actual rates of ventilation, the figures used were considered acceptable. Initial tests of the model (see Section 5.2) also supported the values chosen.

The choice of internal air temperature was, in contrast, a simpler task. Again, design values are used so that unacceptably high temperature levels would be highligted by the difference between actual and predicted energy consumption. Obviously it is necessary to take into account the needs of the occupants in arriving at a suitable design temperature and this is reflected in the choice of 21°C for old peoples' homes as opposed to 19°C for school and office buildings. These are not 24 hour average values but are the temperatures required during the occupancy period. The model itself calculates the 24 hour average (see Section 3.3).

In the case of schools the CIBS Guide gives design temperatures of 19°C for classrooms but 18°C for assembly rooms, sports halls and workshops. Although it would be possible, for the purposes of calculation, to split a school into its separate zones this was not considered worthwhile because the difference in design temperatures is only 1°C . The Guide also suggests a figure of 22°C for residential buildings such as old peoples' and childrens' homes, however because much of the areas of these homes is taken up by laundry rooms, kitchens and other utility rooms which do not require such a high temperature standard it was decided that an overall figure of 21°C should be used.

Incidental Heat Gains

In accordance with the guidelines laid out in the CIBS Energy Code (32) it was decided that the only non-solar incidental heat gains that should be considered are those from artificial lighting and body heat. The computer program ENGY (7) also allows consideration of gains from the hot water supply and cooking but in a non-domestic situation these gains are likely to be too localised to be considered useful.

The values for heat gains from human bodies and artificial lighting have, in general, been taken from the CIBS Guide Section A7 . With a knowledge of the floor area of the building, hours of occupation and number of occupants the contribution of these gains can be calculated as shown in Section 3.6.

One problem encoutered was that, by assuming the whole floor area of a building to be lit for the complete duration of occupancy, the heat gains from artificial lighting calculated for old peoples' homes were too great. The need for adjustment of the heat gain per square metre assumed for old peoples' homes was discovered during the initial verification of the model described in Section 5.2.

Energy Consumption of Other Utilities on the Same Meter as Space Heating

In many of the buildings currently held on the ENMAN system hot water and cooking consumption are not metered seperately from space heating and so it was necessary to make some estimate of the consumption of these utilities to allow the comparison of calculated energy requirement with meter readings. None of the buildings are heated by electricity therefore it was not necessary to make any estimate of lighting consumption.

Statistical averages of hot water consumption have been used and are taken from Jones' paper (38) which lists the consumption of hot water in litres per person per day for the full range of occupancy types. A temperature rise of 55°C is assumed to allow the calculation of energy consumption as shown in Section 3.6.

There is little published material on the subject of cooking consumption and the use of energy depends so much on the type of meals and numbers being cooked at each sitting . For example, in terms of consumption per meal cooked, it is far more efficient to be cooking for large numbers of people as in a school. There may be no consumption if cold salads or sandwiches are being served. In schools the pattern of school meal provision is constantly changing and there is a trend towards less cooked meals being provided.

The figured used for cooking consumption are largely loose estimates but with some advice from Catering Managers in the Council's Education and Family and Community Services Departments on the type of meals cooked and appliances used. In the context of total energy requirement there is not expected to be too great an error caused by the under or over-estimation of cooking consumption becuse it is generally a relatively small proportion of the total usage.

Hours of Occupation

The hours of occupation of a building can obviously have a significant effect on energy requirement when intermittent heating is used. Old peoples' homes are generally heated continuously for 24 hours a day, seven days a week. Schools require heating not only during school hours but often during the evening when events such as night classes are taking place.

The occupancy hours are described by the user of the ENMAN system in terms of an average number of hours per day and days per week. These two figures are used at various stages in the calculation of energy requirement. e.g. for calculating a modified base temperature and intermittency factor and for determining the magnitude of incidental heat gains.

3.5 THE CALCULATION OF SOLAR GAINS

The ENMAN computer program makes use of the recently developed EEC solar gain prediction method (18) which uses meteorologically based calculation techniques. Mathematical predictions are made of hourly and daily values of solar radiation falling on inclined surfaces under clear conditions and, seperately, under overcast conditions. To arrive at a prediction for the mixed conditions prevalent in our climate the overcast and clear sky predictions are proportioned according to observed daily durations of bright sunshine. The hours of bright sunshine is a figure readily available from most meteorological stations.

In previous methods (6 , 39) predictions have been linearly proportioned :

$$\Sigma G_m = S \Sigma G_{cl} + (1 - S) \Sigma G_{oc} \qquad 3.5.1$$

where, ΣG_m is the daily total of monthly mean global irradiation, or the total daily solar energy received in Wh/m^2

G_{cl} , G_{oc} are the hourly values of the clear sky and overcast sky irradiances in W/m^2

S is the ratio of observed hours of bright sunshine to the maximum possible number of sunshine hours.

However, recent work (40) has shown that it is more correct to apply proportioning factors which vary with solar altitude because the sun is less likely to be obscured at high solar altitudes when clouds form a smaller angle of obstruction. This theory of 'Relative Sunshine Probability' is incorporated into the EEC model.

The problem with the calculation procedure documented in the EEC method is that a change in S demands a complete recalculation of solar gains which was not necessary using linear proportioning. For energy management purposes the EEC method , as it stands , would imply the need for very complex calculations each month and for every building requiring investigation. Fortunately it is possible to rearrange the procedure to allow minimal recalculation each month. Appendix IIA describes how S can be kept outside the calculation and shows that 'relative sunshine probability' is actually a quartic proportioning of overcast sky and clear sky predictions where the following equation applies :

$$\sum G_m = a_{4m} S^4 + a_{3m} S^3 + a_{2m} S^2 + a_{1m} S + a_{om} \qquad 3.5.2$$

where, a_{4m} , a_{3m} , a_{2m} , a_{1m} , a_{om} are functions of G_{oc} and G_{cl}
subscript m denotes month

The total daily solar heat gain H_s (Wh) is found by summing for each different glass orientation such that,

$$H_s = b_{4m} S^4 + b_{3m} S^3 + b_{2m} S^2 + b_{1m} S + b_{om} \qquad 3.5.3$$

where,

$$b_{4m} = \sum_{f=1}^{n} a_{4m} A_{gf}$$

$$b_{3m} = \sum_{f=1}^{n} a_{3m} A_{gf} \qquad \text{etc.}$$

f denotes facade number
n is the total number of glass facades
A_{gf} is the area of glass in each facade (m^2)

The total of sixty coefficients , five for each month of the year, are fixed for a particular building and site and may be precalcualted for each building making subsequent calculations of H_s extremely fast.

The EEC method can be further streamlined for the purposes of this project because all the buildings under investigation lie within a fairly confined area and there is little accuracy lost in assuming that solar geometry and horizontal irradiances are the same for each site. These are , in fact, calculated once and stored on a disk file for later use. The calculation procedure, as revised for use in the ENMAN computer program, is now split into three stages :

(i) The calculation of solar geometry and horizontal irradiances for the site area (Sheffield in this project). This is performed by a computer program developed as part of ENMAN and called SOL.

(ii) Calculation of inclined surface irradiances and solar coefficients using data from step (i) with correction for glass transmission. This calculation is carried out during the pre-processing of data for each building as described in Section 4.3 .

(iii) Monthly calculation of the average total daily solar gain using equation 3.5.3 .

Corrections for Glass Transmission

It is well known (41 , 42) that the transmission coefficient or transmittance of a particular type and thickness of glass is not constant but depends both on the wavelength of the light concerned and the angle of incidence with which the light strikes the pane of glass.

It would probably be sufficient to apply a simple transmission coefficient of 0.80 for single glazing but, because the EEC solar gain prediction method already involves the numerical integration of over two thousand zones of the sky vault, little extra work is needed to apply the correct transmittance based on the angle of incidence each zone makes with the glass normal. Appendix IIB describes the algorithms used for this correction.

3.6 SUMMARY OF THE CALCULATION PROCEDURE

3.6.1 Building Input Parameters

	symbol	units
(1) Sum of fabric heat losses	$\leq AU$	$W/^oc$
Floor area (which is heated)	A_{fl}	m^2
Enclosed volume	V	m^3
(2) Estimate a response factor for the building according to a subjective decision about its thermal weight	f_r	-
e.g. lightweight $1 < f_r < 3$		
medium $3 \leq f_r < 6$		
heavy $f_r \geq 6$		
(3) Glazing details :		
orientation of each facade from South	α_f	deg.
inclination angle of glazing	β_f	deg.
glazed area per facade	A_{gf}	m^2
subscript f denotes facade number		
(4) Occupancy :		
number of occupants	N_{ocp}	-
occupancy hours per day	h_{ocp}	hrs.
number of days per week	d_{ocp}	days
(5) Parameters associated with functional use :		
design air temperature during period of occupation	t_d	^oc
ventilation rate (24hr average)	n	ac/hr

	symbol	units
lighting heat output rate per unit floor area (includes correction for proportion of floor area which is lighted and proportion of occupation period lighting is used)	L	W/m^2
hot water consumption per person per day	W	kg/day
cooking consumption per person per day (corrected for the proportion of occupants taking hot meals)	C	kWh/day

These parameters are specified by the 'type' classification of the building,

e.g. TYPE 1 (SCHOOL) implies

t_d = 19 °C

n = 1 ac/hr

L = 10 W/m^2

W = 6 kg/person/day

C = 0.2 kWh/person/day

a full list of these classifications is given in Table 3.1

3.6.2 Climatic Parameters

Daily values of the maximum and minimum outside air temperatures, t_x and t_n are obtained from the local weather station together with the monthly total of hours of bright sunshine.

3.6.3 Preliminary Calculations

These calculations are a pre-processing of the building data which is performed to simplify the subsequent monthly calculations. Section 4.3 explains how computer time is saved by doing this.

(1) Calculate the total sum of fabric and ventilation heat losses :

$$(q_f + q_v) = \sum AU + 1/3\ nV \qquad (W/^{o}C) \qquad 3.6.1$$

(2) Monthly non-solar incidental heat gains :

$$H_1 = N_s \,(\, \underbrace{A_{fl}\, L\, h_{ocp}}_{\text{lighting}} + \underbrace{Q_b\, N_{ocp}\, h_{ocp}}_{\text{body heat}} \,)/1000 \quad \text{(kWh)} \qquad 3.6.2$$

where, N_s is the number of days in the month

Q_b is the sensible heat output from a human body (taken as 75 W)

(3) Solar gain coefficients b_{4m} , b_{3m} , b_{2m} , b_{1m} , b_{om} are calculated for each month of the year using the procedure described in Section 3.5 .

(4) Monthly energy consumption of other utilities (hot water and cooking) are calculated when they are included in the same meter reading as space heating :

$$H_u = N_s \,(d_{ocp}/7)\, (W\, N_{ocp}\, t_w c_w /3600 + C\, N_{ocp}\,) \quad \text{(kWh)} \quad 3.6.3$$

where, t_w is the temperature rise of hot water (taken as 55^oC)

c_w is the specific heat capacity of water ($4.2\ kJ/kg^oC$)

3.6.4 <u>Calculation of Monthly Energy Requirements</u>

(1) Calculate the intermittency factor, B :

$$B = \frac{h_p\ f_r}{h_p\, f_r + (\ 24 - h_p\ )} \qquad 3.6.4$$

where, h_p is the heating plant 'ON' time per day

$$h_p = h_{ocp} + h_{preheat} \qquad \text{(hrs)}$$

$h_{preheat}$, the preheat period in hours, is tabulated as a function of f_r in Table 3.2 (taken from the CIBS Energy Code (32)).

(2) Calculate t, the temperature reduction caused by incidental heat gains :

$$t = \frac{1000\ (\ H_1 + H_2\ )}{24\ N_s\ (\ q_f + q_v\ )} \qquad (^{o}C) \qquad 3.6.5$$

where,

$H_2 = 1000\ N_s\ (\ b_{4m}S^4 + b_{3m}S^3 + b_{2m}S^2 + b_{1m}S + b_{0m}\ )$,
the monthly mean solar heat gains (kWh).

(3) The degree-day base temperature is given by

$$t_b = t_d - t\ /\ B \qquad (^{o}C) \qquad 3.6.6$$

(4) Calculate the degree-days for each day of the month using the empirical equations of Figure 3.2 and sum to give the monthly total $D(t_b)$.

(5) The monthly space-heating energy requirement is given by :

$$H_p = (24/1000)B\ (\ q_f + q_v\ )\ D(t_b)\ (d_{ocp}/7) \qquad (kWh) \qquad 3.6.7$$

(6) The total monthly energy requirement for comparison with meter readings is then given by :

$$H_{total} = (\ H_p + H_u\ )\ /\ \eta_p \qquad (kWh) \qquad 3.6.8$$

where, η_p is the overall efficiency assumed for the heating plant and distribution system (a target figure is used).

DESCRIPTION OF USAGE	'TYPE' CLASSIFICATION	t_d °C	n ac/hr	L W/m^2	W l/person	C Wh/person
SCHOOL	1	19	1.0	10.0	6	200
OLD PEOPLES' HOME	2	21	1.0	2.5	130	250
SHELTERED HOMES	3	21	0.8	2.5	130	300
OFFICE with canteen facilities	4	18	1.0	10.0	9	250
OFFICE without canteen	5	18	1.0	10.0	4	0

TABLE 3.1

Parameters associated with building 'type'

Thermal response f_r	Preheat time (hours)	
	Optimum start	Fixed start
< 2.5	2	3
2.5 to 6.0	3	4
6.0 to 10.0	4	5
> 10.0	5	6

TABLE 3.2

Preheat times

3.7 JUSTIFICATION FOR THE CHOICE OF THE ENMAN ENERGY MODEL

The energy requirements predicted by the model described in this chapter are prone to two different types of error :

(i) those due to assumptions made by the model which do not strictly hold in practice, especially those attributed to the Degree-Day method.

(ii) those due to the inevitable inaccuracy of the building parameters which have to be supplied to the model.

The former are only quantifiable by comparison with carefully controlled and monitored real buildings, or by comparison with fully comprehensive dynamic thermal programs or analogue simulations.

Such comparisons have been performed by Spooner (34) , Hitchin and Hyde (24) and Jones (14). Spooner compared the monitored energy use of a test house with the predictions of several simple energy models including the degree-day method. His conclusions were that the differences between predicted and actual consumption could be more than accounted for by the uncertainty involved in the calculation of U-values and by the presence of cold bridging which was difficult to allow for in the calculation of $\sum AU$.

Hitchin and Hyde have compared energy requirements calculated using the Degree-Day method with those from the computer program THERM, which incorporates a dynamic model of thermal behaviour. They found a discrepancy of 7% and suggested that this was largely due to the assumption, made by a variable base degree-day method, that all solar gains are useful.

Jones performed several comparisons between the dynamic model embodied in the computer program TAS$^{\circ}$ and the Degree-Day method. He observed discrepancies of up to 13% and suggested that the Degree-Day method suffers due to its incorrect consideration of the effects of thermal capacity and solar gain.

Appendix III shows a comparison between four different calculation methods for an example building. The predictions of energy requiremnt are summarised as follows :

(1) CIBS Admittance Method	24900 kWh
(2) Billington's Method	28092 kWh
(3) Water's Method	22830 kWh
(4) The ENMAN Method	25100 kWh

All the methods predict energy requirements within ± 11% of the ENMAN method.

It is suggested that the levels of disagreement quoted above are quite acceptable for the purposes of performance monitoring because it is shown in Appendix III that typical errors in the specification of input parameters can have a much greater effect.

Because of the possibility of cold bridging, the problems of specifying material properties and the difficulty in specifying U-values and Admittance factors for ground floors possible errors of 20% have been used for ΣAU and ΣAY. Together with typical inaccuracies of 20% for incidental heat gains and 1 hour for the occupancy period, these errors could produce a combined error of 31% in the final prediction of H_p.

Other conclusions which may be drawn from Appendix III are that

(i) errors in the specification of ΣAY may be as high as 50% before they have the same effect as a 20% error in ΣAU. It is for this reason that it has been suggested that, rather than calculating ΣAY explicitly, a value for f_r may be estimated from a qualitative appraisal of a building.

(ii) errors in the determination of incidental heat gains and hours of occupancy are also less significant. However, these parameters can become more significant for other types of building and for other times of year. It is also relatively easy to specify these parameters with a large discrepancy from their true values. This last problem was discovered during the initial verification of the ENMAN model described in Chapter 5.

CHAPTER 4

IMPLEMENTATION OF THE FORTRAN COMPUTER PROGRAM ENMAN

4.1 INTRODUCTION

The FORTRAN program ENMAN consists of a suite of four programs :

BUILD enables a user to input the details of each building requiring investigation. Information which is already on file can be edited or deleted. Additional buildings may be described at any time.

UPDATE allows the monthly updating of fuel consumption records and weather data. The information may be edited at a later date if required.

ENMAN1 produces a monthly printout of the comparison between calculated fuel requirements and actual fuel usage. The fuel usages are also stated per unit floor area for further comparative analysis. All the buildings which have previously been described using program BUILD are analysed.

ENMAN2 produces more detailed comparisons of energy consumption and is used to investigate individual buildings over long time periods. With the aid of graphics, ENMAN2 becomes a useful tool for illustrating long term trends in energy consumption which may not have been immediately evident with purely numerical presentations. The program is completely interactive and results are presented in both graphical and tabular form on a computer terminal.

The relationship between the four programs is illustrated in Figure 4.1 . BUILD and UPDATE are used to create a database of information which can be read by ENMAN1 and ENMAN2 enabling them to produce comparisons between predicted and actual fuel consumptions.

All the programs are written in ICL Standard Fortran and make use of the GINO-F (43) and GINOGRAF (44) general purpose graphics packages. ENMAN is designed to run on a Tektronix 4014 storage tube terminal of which there are many emulators from other manufacturers such as DataType, ACT Sirius and Westward. Because of the device-independent nature of the GINO packages it would be a straightforward task to adapt the program to run on a number of other graphics terminals.

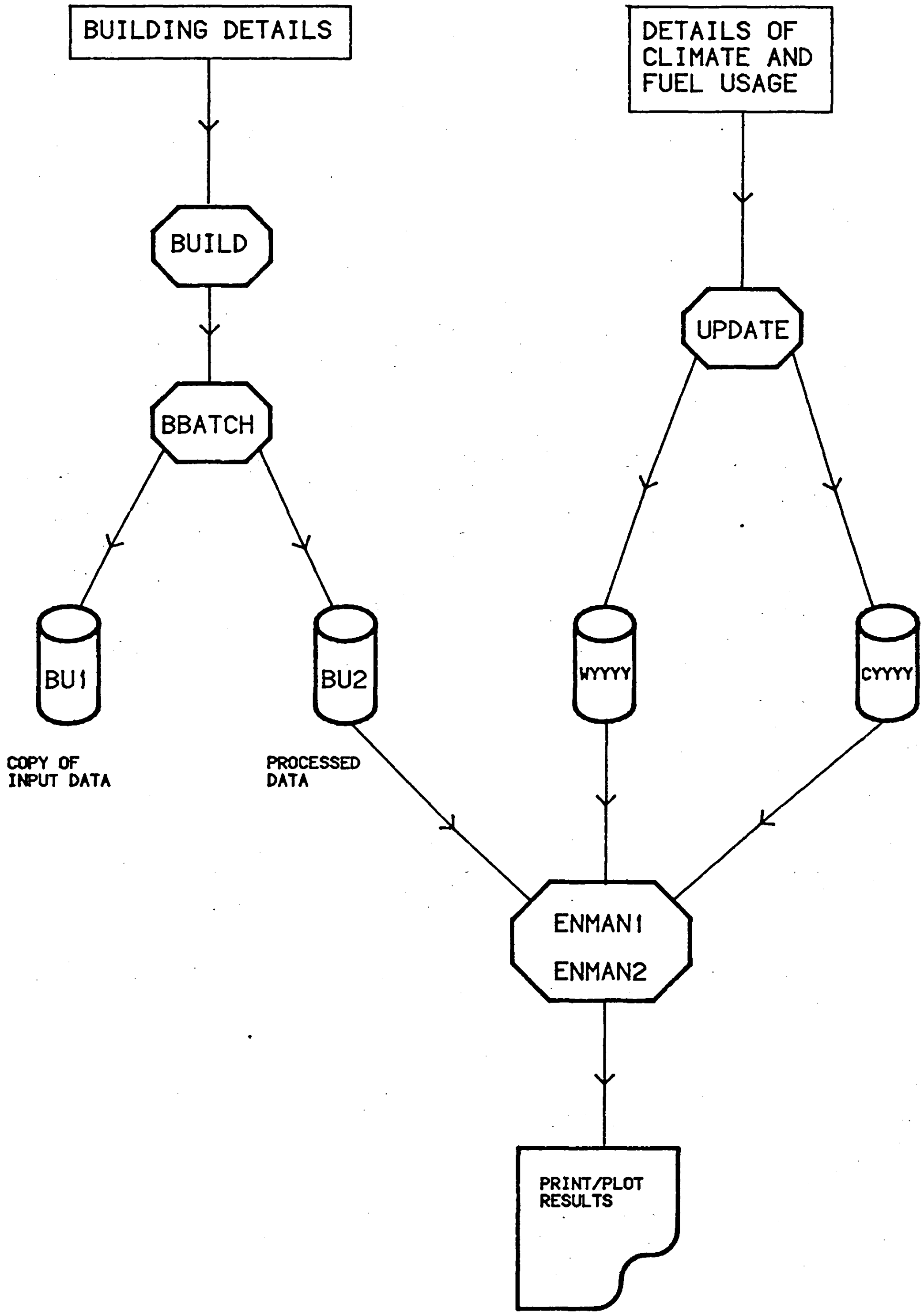


FIGURE 4.1

ENMAN - COMPLETE SYSTEM DIAGRAM

4.2 MENUS AND COMMAND STRUCTURE

General

To make the ENMAN programs simple to operate a system of menus is used. The advantage of using a menu system is that the user can move with great ease between the commands available in different parts of each program. Programs which are not controlled by menus generally have a tree structure as illustrated in Figure 4.2 . Although different paths may be taken through such programs by making decisions at junction points, the flow of information is unidirectional because paths cannot usually be retraced. With a menu system it becomes possible to loopback and reenter information or choose a different form of output witout having to restart at the top of the tree, this is an essential feature of any truly interactive program.

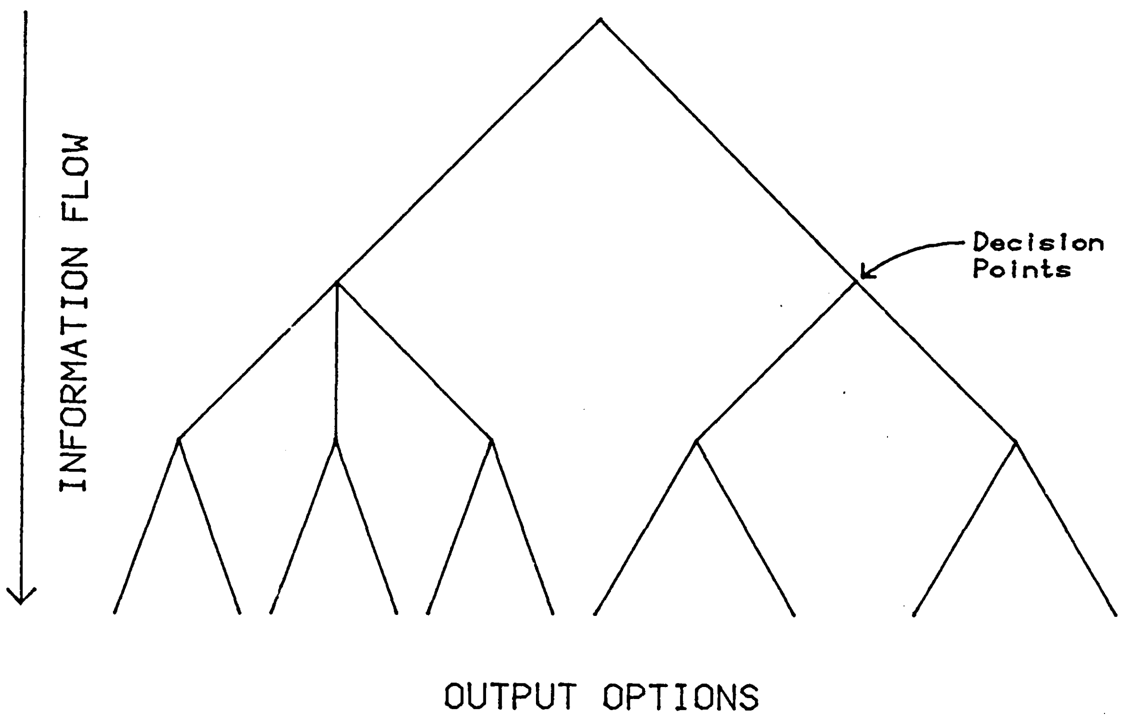


FIGURE 4.2 The 'Tree' Structure of Programs Not Controlled by Menus

Because Council staff were already familiar with the menu system of the ENGY program it was decided to adopt a similar format for ENMAN. The commands available in each section of the program are arranged in a menu and a particular command may be chosen by placing a thumbwheel controlled cursor over that command. The programs UPDATE and BUILD have ,respectively, two and three-tier menu systems where certain commands lead into sub-menus;the user may return to a higher tier at any time by choosing the EXIT command. ENMAN2 has just one menu to control the output of results. ENMAN1 does not require interaction with the user because the only parameter necessary to run the program is the date (month and year) for which printout is required. The structure of commands in each of the three interactive programs is illustrated in Figures 4.3 , 4.4 , 4.5 , a description of each individual command is given below.

<u>Program BUILD</u> (see Figure 4.3)

The BUILD menu is entered on commencing the run of the program. The commands available in this first menu are :-

NEW - transfers control to the NEW sub-menu for the initial description of a building.

OLD - allows details of buildings which are already held on file to be altered. A further menu is generated containing the following commands :

BUILDING - specifies the building for which information is to be altered. The building must be held on file and is selected by entering either the first six letters of its name or its six letter code.

UPDATE - this command is used when a change in the physical parameters of the building or its occupancy take place at a particular date e.g. the building is cavity insulated. Control is transferred to the UPDATE/EDIT menu.

EDIT - this command is used when previously stored information has been found to be incorrect e.g. the enclosed volume of a building may have been entered as 4500 m^3 when it should have been 5400 m^3. The command transfers control to the UPDATE/EDIT menu.

DELETE - the building specified by the BUILDING command is deleted from filestore. The user is given additional warnings before the building is deleted in case the command was chosen by mistake.

EXIT - returns control to the BUILD menu.

END - ends the running of BUILD and returns control to the computer's operating system.

The NEW and UPDATE/EDIT menus are identical and contain the following commands :-

BUILDING - allows the user to give a name to the building being considered. A name of up to forty characters is entered together with a six letter reference code.

TYPE - sets the 'type' classification of the building (see Section 3.4) which describes the functional usage of the building.

FLOOR - sets the overall heated floor area of the building (m^2) This is required for the estimation of heat gains from artificial lighting and the calculation of fuel usage per unit floor area.

VOLUME - sets the internal volume of the building (m^3)

OCCUPANCY - sets the number of occupants and the occupancy pattern in hours per day and days per week.

FR - sets the response factor of the building.

AU - sets the total fabric heat conductance of the building, AU , in W/^{o}c .

GLASS - sets the area, orientation and inclination of glass in each facade of the building. For ease of use, the orientation may be entered as a point of the compass , e.g. 'NE' , or explicitly as the number of degrees from South.

FUEL - specifies the heating fuel used. The user specifies the name of the fuel and its units, its calorific value (kWh/unit) and the expected efficiency of the heating system.

LIST - produces a list of all information which has been entered

EXIT - the user is asked whether he requres the information entered to be made permanent, control is then returned to the previous menu.

In the case of a 'new' building, all the information listed above must be supplied before data may be stored. With an 'old' building, all the existing information is read in and commands only need to be chosen for those parameters which are to be altered.

Program UPDATE (see Figure 4.4)

The first menu of the UPDATE program contains three commands :-

WEATHER - transfers control to the WEATHER menu for the updating of climatic data. The following commands are available in this sub-menu :

- MONTH - specifies the month (1 - 12) for which weather data is to be added or edited.
- YEAR - specifies the year.
- UPDATE - allows the user to enter climatic data for a complete month. The user is invited to enter maximum and mininmum air temperatures for each day and finally the monthly total of hours of bright sunshine.
- LOOK - lists all the data held for the specified month
- EDIT - allows the user to alter climatic information for those months already on file.
- EXIT - returns control to the UPDATE menu.

FUEL - transfers control to the FUEL sub-menu which contains the following commands :

- AUTO - allows the user to enter actual fuel consumptions for the specified month for all buildings held on the building database.
- BUILDING - specifies an individual building which is to have its consumption records updated, edited or listed.
- ADD - for the specified building the user may add to existing data by entering monthly fuel consumptions.

EDIT - allows the user to edit previously supplied data e.g. the faciltity may be used to correct estimated meter readings if their true value becomes known at a later date.

LIST - produces a list of any twelve months consumption data for the specified building.

EXIT - returns control to the UPDATE menu.

END - returns control to the computer's command system.

<u>Program ENMAN2</u> (see Figure 4.5)

This program has six different forms of output which can be produced from the analysis of an individual building. Output may be produced for any time period for which weather and fuel consumption data are available. The program has just one menu containing the following commands :-

BUILDING - specifies the building for which analysis is required.

START - specifies the date (month and year) of the first month of analysis.

TABLE1 - produces a detailed breakdown of energy requirement calculations for a period of twelve months.

TABLE2 - produces a tabular comparison between calculated energy requirement and actual fuel consumption over a period of twelve months. Monthly, cumulative and moving yearly total consumptions are compared.

PLOT1 - produces a graphical comparison over a twelve month period of monthly energy consumption.

PLOT2 - produces a graphical comparison over a two year period of moving yearly totals of energy consumption.

PLOT3 - produces a 'Z - chart' for a twelve month period showing cumulative energy consumption plotted on the same scale as moving yearly totals.

PLOT4 - produces a plot actual fuel consumption versus calculated fuel requirements. Up to thirty-six months' comparisons may be plotted and a least squares best fit line is drawn through the plotted points.

END - returns control to the computer's operating system.

The operation of ENMAN2, BUILD and UPDATE are shown, by means of example, in Section 4.5 .

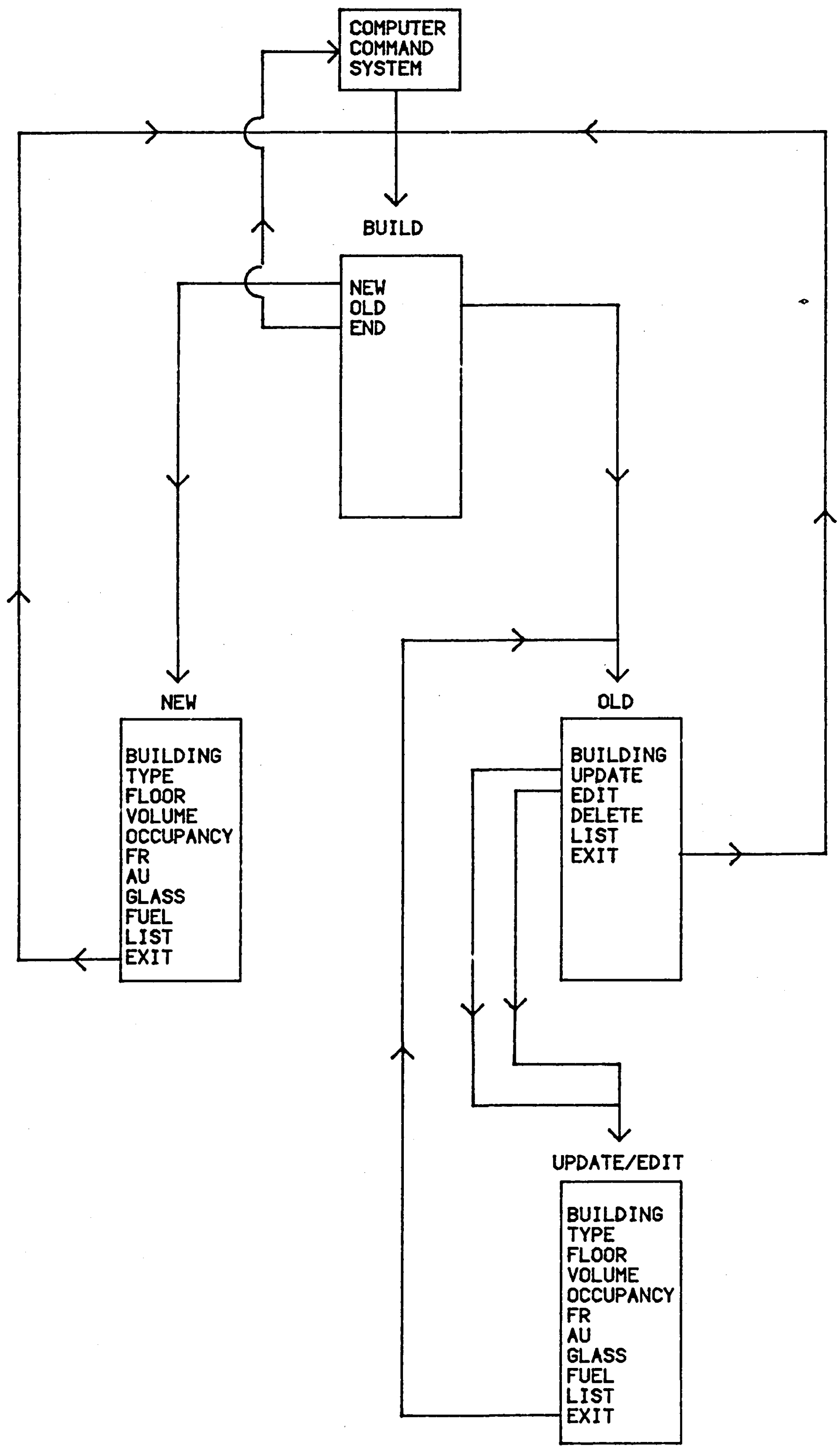


FIGURE 4.3

Menu System for Program BUILD

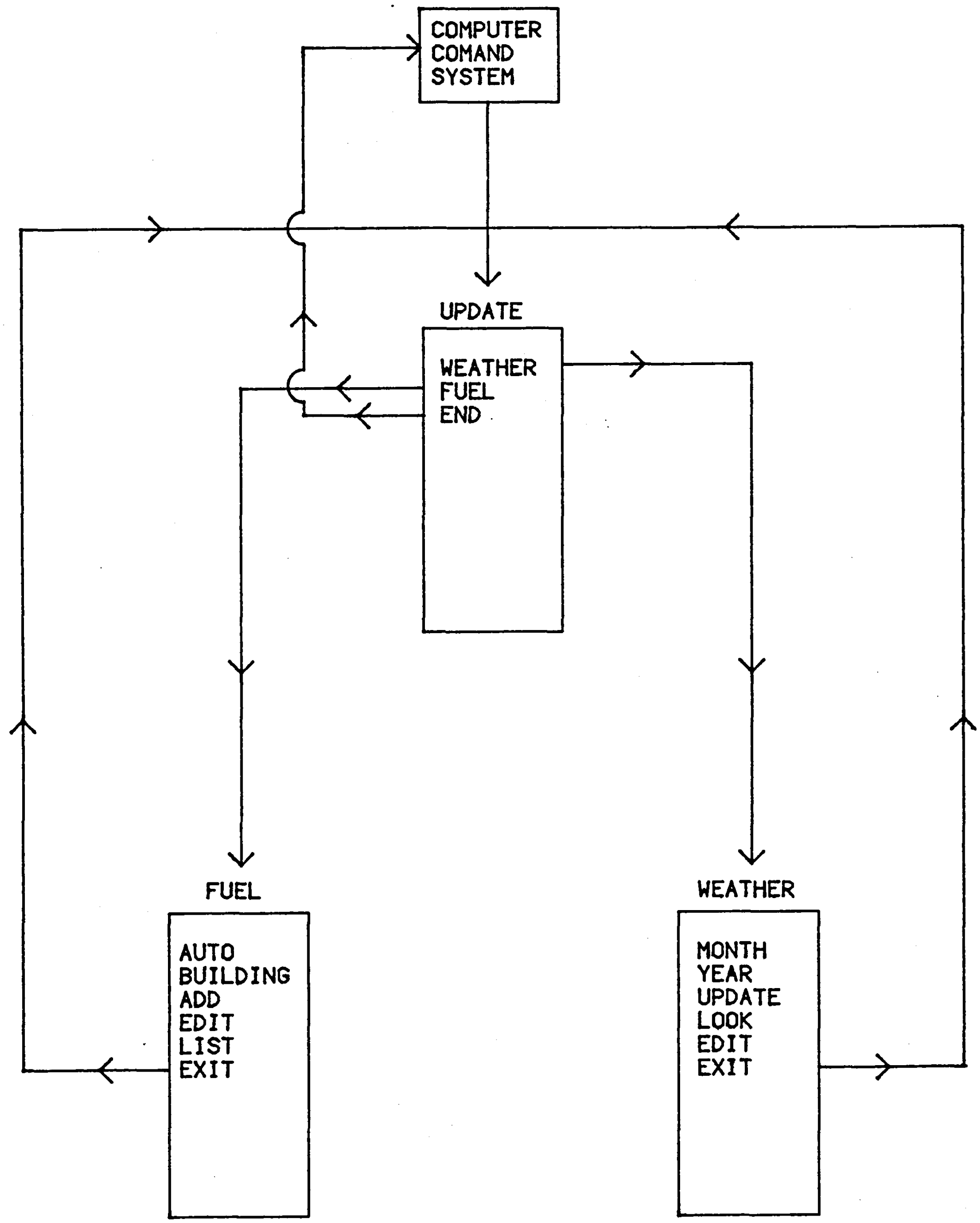


FIGURE 4.4

Menu System for Program UPDATE

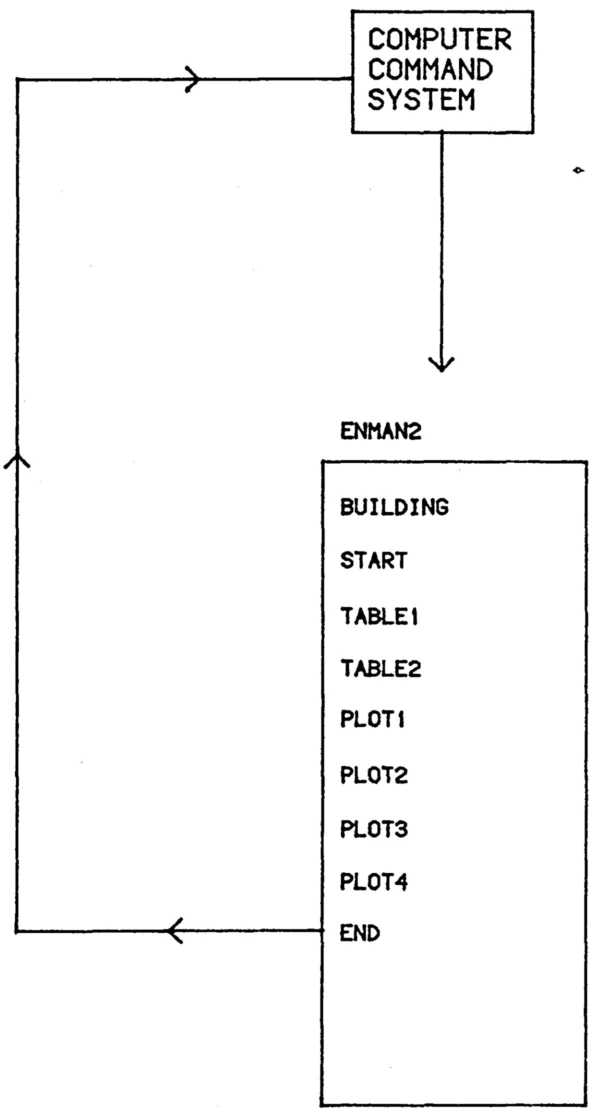


FIGURE 4.5

Menu System for Program ENMAN2

4.3 DATABASE STRUCTURE AND FORMATION

General

As shown in Figure 4.1 , there are four different sets of data which form the complete database for the ENMAN system :-

- BU1 is a file which stores all the physical details and occupancy patterns supplied by the user for each building.
- BU2 this file stores a processed form of the data held in BU1 . The reasons for having a separate file are described below.
- CYYYY these are a group of files, C1980, C1981, C1982 etc. , which each store twelve months fuel consumption information for all the buildings held on the database.
- WYYYY these are a similar group of files , W1980, W1981 etc. , which each hold up to twelve months weather data - maximum and minimum daily air temperatures and monthly totals of hours of bright sunshine.

In addition there is an INDEX file. Because BU1 , BU2 and CYYYY hold information for every building under investigation it is necessary to use an index to quickly locate details for a particular building.

Building Database

Figure 4.6 shows overall process for the creation of the buildings database.

The information required by ENMAN is first collected and entered onto a worksheet (see Figure 4.7). By using commands from the program BUILD this information can then be entered into the computer.

The building details are initially stored on the temporary file , TEMP , which can stack up data for a number of buildings. In order to economise on computer time, the building data held on file TEMP is processed to create another data file, BU2, containing the information required for calculating energy requirements. The pre-processing of the data takes account of the following factors :-

(i) Incidental heat gains from sources other than the sun are assumed to be constant throughout the year and so they can be precalculated for each building. The factors affecting these heat gains are the number of occupants, the hours of occupancy, floor area and the building 'type'.

(ii) Solar Gains can be set up as a set of sixty coefficients for each building as described in Chapter 3.

(iii) The total heat conductance of the building, including fabric and ventilation heat losses, can be calculated from $(q_f + q_v) = \sum AU + 1/3\ nV$ where, n is the average ventilation rate associated with the building 'type'.

(iv) Energy consumption of utilities such as hot water and cooking are assumed constant for each day of occupation. This consumption can be pre-calculated, where necessary, from a knowledge of the building 'type' and the number of occupants.

All these calculations have been summarised in Section 3.6 and are performed once the run of BUILD has finished. Because of the complexity of the solar gain calculations the program BBATCH, which performs these calculations, is run in batch mode. The program runs in background without interaction from the computer terminal ; the mainframe computer itself decides, on a queue system, when the program is actually run.

The processed form of the data is stored on the file BU2 . A permanent copy of the information on the TEMP file is also added to the file BU1 . Although this original information is no longer required for any subsequent energy analysis , it is kept so that the input information can be listed or edited at a later date.

Weather and Consumption Database

Weather data is taken from sheets supplied monthly by our local weather station at Weston Park museum. Figure 4.8 shows an example of one of these sheets. Information is added to the database using commands from the WEATHER menu of program UPDATE.

The consumption files C1980, C1981 etc. are updated or edited by using commands from the FUEL menu of program UPDATE. Each file holds up to twelve months' records of actual fuel consumption for all buildings held on the building database. The files are structured in the following way :-

RECORD 1 (header): YYYY , NBLDGS

RECORD 2 (1st building): C6 , CONS(1),CONS(2),...,CONS(12) , C12

RECORD 3 (2nd building) "

etc.

where, YYYY is the year

NBLDGS the number of buildings whose consumption records are held on the file

C6 the building name abbreviated to its first six characters

C12 is a string containing twelve comment characters , one for each month , e.g. if a consumption is estimated then an 'E' is stored as a reminder on printout.

C6 is only used for reference in direct listings of the consumption files - the location of each building is already known from the INDEX file described below.

Index System

Because of the limitations imposed by the ICL operating system it was decided that the files BU1 , BU2 and C1980 , C1981 etc. should each contain information for all buildings rather than having a separate file for each individual building. Data for individual buildings are located within these files by using an index system.

The INDEX file is structured as follows :-

Record 1 (header)   NBLDGS

Record 2 (1st building) BNAME, BCODE, VERS, DATE1, DATE2, LOC1, LOC2

Record 3 (2nd building)   "

etc.

where, NBLDGS is the number of buildings held on the INDEX file.

BNAME the building title.

BCODE the building's six letter reference code.

VERS the version number of the building (see below)

DATE1 and DATE2 are the two dates between which this version applies.

LOC1 is the location of the building in files BU1 and BU2.

LOC2 is the location of consumption data in C1980,C1981 etc.

An example of the INDEX file could thus be :-

4

GREEN OAK VIEW O.P.H.	FCS100	1	1	500	4	3
HAWKHILLS O.P.H.	FCS101	1	1	33	1	1
HAWKHILLS O.P.H.	FCS101	2	33	500	3	1
HIGH GREEN COMPREHENSIVE	ED510	1	1	500	2	2

Note that DATE1 and DATE2 are indicated as a number of months from a January 1980 origin (the first month for which analysis is available) such that 33 indicates October 1982.

The index is kept alphabetically so that, during a run of ENMAN1, output can be produced alphabetically by stepping, building by building, down the INDEX file.

There may be more than one 'version' of a particular building. For example, if a building was cavity insulated in October 1982 then there would be one set of building data which applies up to that date and anoother version, holding a lower value for the heat conductance of the building, to apply for all subsequent dates. DATE1 and DATE2 store the dates between which each version is valid. The creation of such extra 'versions' is achieved using the UPDATE command from the OLD menu of program BUILD.

In the above example, Hawkhills Old Peoples' Home has two versions, one applying between dates 1 and 33 (indicating Jan. 1980 and Oct. 1982) and the other between dates 33 and 500 (Oct. 1982 to an unspecified date in the future). The two versions share the same consumption data and so have identical values for LOC2 but are stored as two separate buildings in the files BU1 and BU2. It can be seen from the example index that the chronological order in which the buildings were described and stored in BU1 and BU2 is thus : Hawkhills O.P.H. (version 1) followed by High Green Comprehensive, Hawkhills (version 2) and Green Oak View Old Peoples' Home.

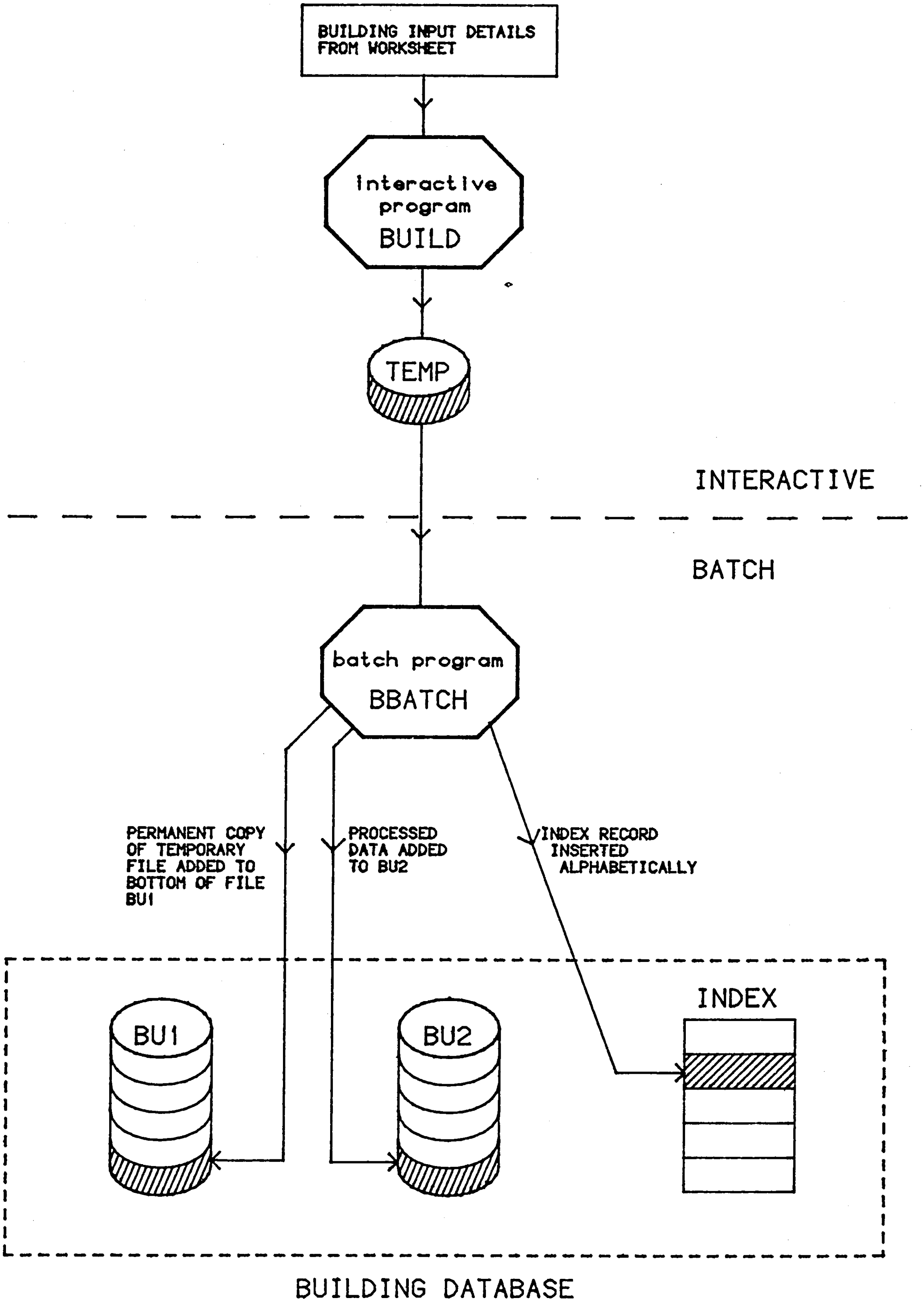


FIGURE 4.6

Creation of the Buildings Database

BUILDING :

CODE :   TYPE :

FLOOR AREA (M^2) :   VOLUME (M^3) :

FABRIC HEAT LOSSES

	AREA (M^2)	U-VALUE (W/M^2DEGC)	A.U (W/DEGC)
WALLS			
GLASS			
ROOF			
FLOOR			
OTHER			
		TOTAL ≤ AU	

RESPONSE FACTOR :

GLAZING

	AREA(M^2)	ORIENTATION(DEG)	INCLINATION(DEG)
1			
2			
3			
4			
5			
6			

OCCUPANCY

APPROX. NO. OF OCCUPANTS :
AVERAGE DAILY HOURS OF USE :
AVERAGE DAYS PER WEEK :

FUEL DETAILS

FUEL TYPE: UNIT:
HEAT CONTENT(KWH/UNIT):   UTILISATION EFFICIENCY:

OTHER UTILITIES ON MAIN METER :

FIGURE 4.7

Worksheet for Building Description

SHEFFIELD CITY MUSEUMS

WESTON PARK METEOROLOGICAL STATION

APRIL 1984

Date	Wind Direction & Knots		Dry Bulb °C	Humidity %	Air Max. °C	Air Min. °C	Rainfall mm	Sunshine Hours
1	NE	6	2.4	80	6.1	-0.4	0.1	5.4
2	NNW	6	3.0	88	9.7	-0.2	tr.	5.3
3	SE	6	4.5	63	8.6	-2.6	-	8.8
4	ESE	3	4.4	71	9.2	-0.7	-	5.9
5	NW	1	6.0	73	9.7	-2.2	0.1	8.8
6	NNW	6	4.8	92	6.8	3.5	2.6	-
7	N	6	5.1	83	8.3	2.7	0.2	2.3
8	NNW	6	7.5	72	10.1	4.2	0.7	1.5
9	Calm		7.8	76	11.0	4.7	0.1	2.5
10	Calm		8.1	58	9.9	1.8	1.6	2.0
11	WNW	8	7.1	85	10.0	6.7	0.3	1.6
12	W	5	7.4	58	11.8	1.8	tr.	10.5
13	S	3	7.8	64	11.9	5.0	-	1.7
14	WSW	12	10.0	64	16.1	3.9	2.7	11.6
15	NNE	8	4.1	85	10.1	3.0	1.6	5.7
16	NW	9	7.7	65	10.6	3.1	-	11.9
17	WNW	3	8.4	55	12.0	2.2	tr.	8.1
18	SSW	5	7.8	71	14.1	4.5	-	0.5
19	SSW	10	11.9	44	15.6	7.8	-	0.3
20	W	7	14.2	70	18.0	10.1	-	5.3
21	SW	18	16.8	51	21.1	9.8	-	12.2
22	NE	2	10.5	81	13.7	8.7	-	0.3
23	ENE	3	9.5	70	17.2	2.4	-	12.1
24	ENE	2	7.5	81	18.8	0.1	-	12.9
25	NNE	2	10.6	74	20.7	3.0	-	12.1
26	NE	3	13.7	45	20.1	3.4	-	13.3
27	NE	1	10.1	77	18.5	6.4	-	10.5
28	SE	4	12.3	47	17.6	2.9	-	12.7
29	ENE	4	10.2	67	15.2	4.7	-	9.0
30	E	2	10.8	63	16.8	3.6	-	10.9
							10.0	205.7

Mean of daily maximum temperatures 13.3
Mean of daily minimum temperatures 3.5
Mean of max. and min. temperatures 8.4

FIGURE 4.8

Weahther data sheet supplied by Sheffield's local weather station

4.4 STRUCTURE OF THE ENERGY ANALYSIS PROGRAMS

In order to make calculations of energy requirement, ENMAN1 and ENMAN2 access the two databases of building information and weather. The building data required for energy calculations are stored on the file BU2 which contains the processed information described in Section 4.3. To make comparisons with actual fuel consumption the database of consumption records is also accessed.

The flow diagrams of Figures 4.9 and 4.10 illustrate the processes of ENMAN1 and ENMAN2 and show the relationship with the data files BU2, WYYYY, CYYYY and the INDEX file.

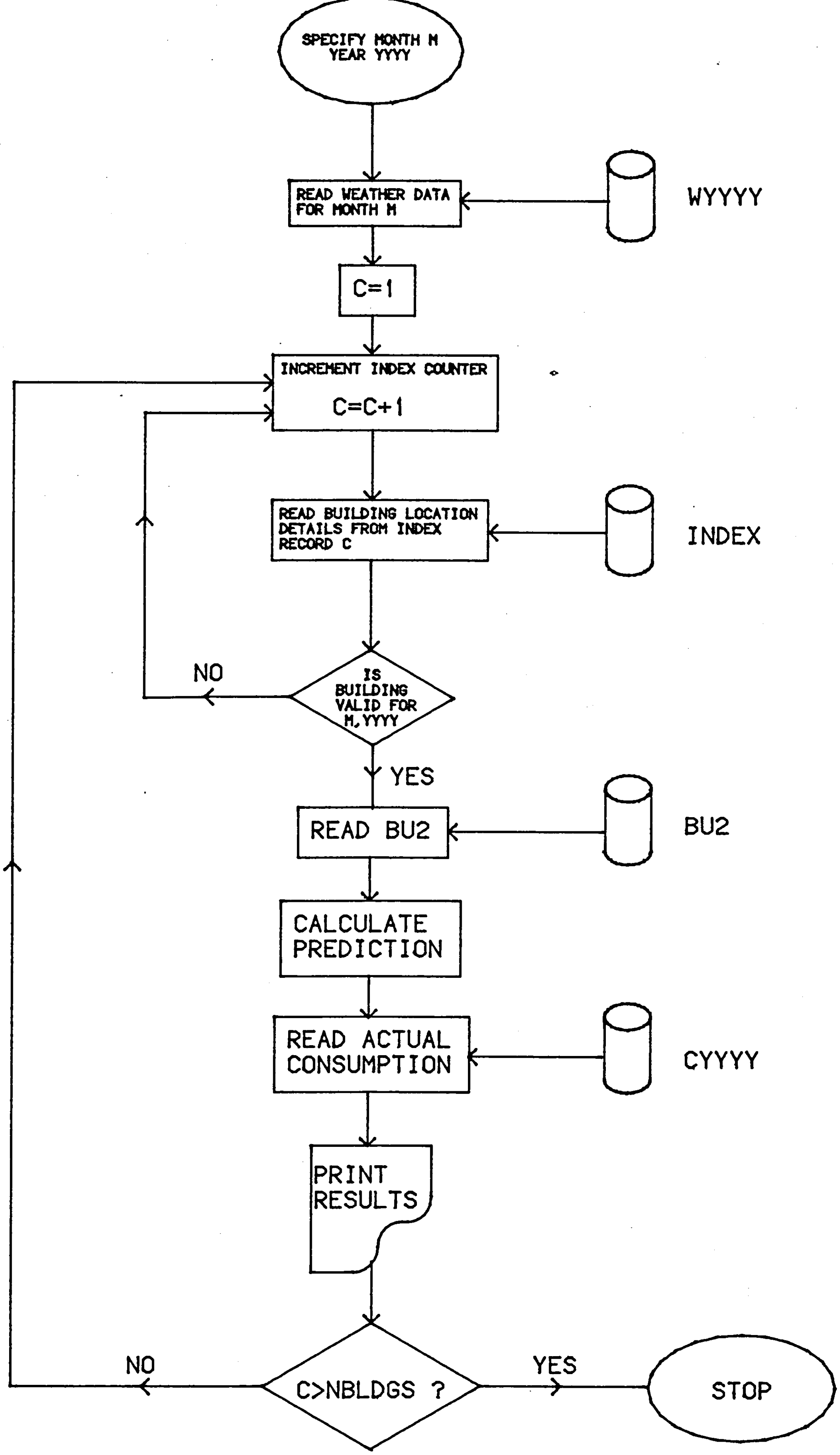


FIGURE 4.9

Flow Diagram for Program ENMAN1

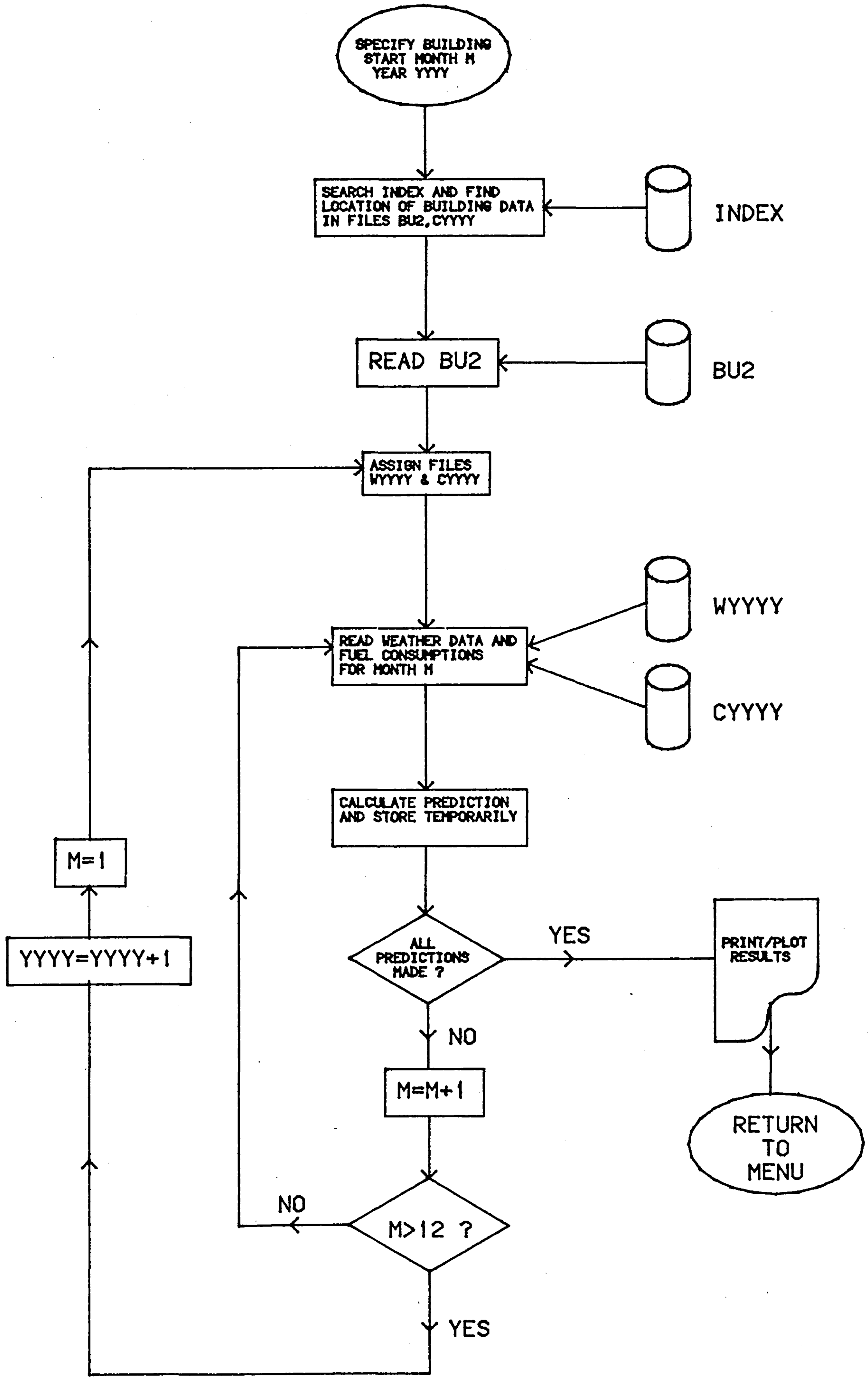


FIGURE 4.10

Flow Diagram for Program ENMAN2

4.5 USING THE PROGRAMS - SAMPLE RUNS OF ENMAN

The operation of the four programs BUILD, UPDATE, ENMAN1 and ENMAN2 is illustrated by sample runs of each program.

BUILD

Figures 4.12 to 4.16 show how High Green Comprehensive School was described to the ENMAN system using details from the worksheet illustrated in Figure 4.11 .

Figures 4.17 to 4.20 illustrate the use of the UPDATE command from the OLD menu of program BUILD to describe the cavity insulation of Green Oak View Old Peoples' Home in October 1981.

UPDATE

Figures 4.21 to 4.24 show how weather data for April 1984 was entered. Information has been taken from the sheet shown in Figure 4.8. Fuel consumption data were also entered for the same month using the AUTO command from the FUEL menu as shown in Figures 4.25 and 4.26.

Figure 4.27 shows how the ADD command may be used to enter information for an individual building. The run of UPDATE is terminated by choosing the END command as shown in Figure 4.28.

ENMAN1

Figure 4.29 illustrates the output from ENMAN1 for April 1982.

ENMAN2

Figures 4.30 to 4.34 show how commands in the ENMAN2 program may be used to produce a variety of output from the energy analysis of individual buildings.

BUILDING : HIGH GREEN COMPREHENSIVE SCHOOL

CODE : ED100 TYPE : 1

FLOOR AREA (M^2) : 4300 VOLUME (M^3) : 11925

FABRIC HEAT LOSSES

		AREA (M^2)	U-VALUE (W/M^2DEGC)	A.U (W/DEGC)
WALLS	panels	407	1·1	448
	brickwork	1950	1·0	1950
GLASS		373	5·6	2089
ROOF		1960	0·55	1078
FLOOR		1960	0·5	980
OTHER				
			TOTAL Σ AU	6545

RESPONSE FACTOR : 6 (medium to heavyweight)

GLAZING

	AREA(M^2)	ORIENTATION(DEG)	INCLINATION(DEG)
1	103	20	90
2	37	110	90
3	101	-160	90
4	72	-70	90
5	20	20	45
6	20	110	45
7	20	-70	45

OCCUPANCY

APPROX. NO. OF OCCUPANTS : 450
AVERAGE DAILY HOURS OF USE : 7·5
AVERAGE DAYS PER WEEK : 5·0

FUEL DETAILS

FUEL TYPE: GAS UNIT:
HEAT CONTENT(KWH/UNIT): 29·3 UTILISATION EFFICIENCY: 60%

OTHER UTILITIES ON MAIN METER : HOT WATER

FIGURE 4.11

Worksheet for the Description of High Green Comprehensive School

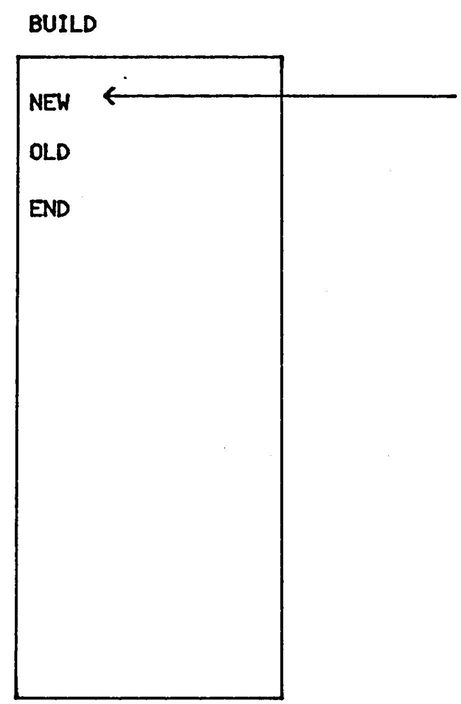


FIGURE 4.12

First Menu of Program Build

NOTES

The user chooses the NEW command using the computer's horizontal cursor.

```
BUILDING NAME (MAX. 40 CHARS.)
/-HIGH GREEN COMPREHENSIVE
BUIDING CODE (6 CHARS.)
/-ED100

BUILDING TYPE
/-1

HEATED FLOOR AREA (M^2)
/-4300

VOLUME
/-11925

APPROX. NO. OF OCCUPANTS
/-450
AVERAGE NO. OF HOURS PER DAY BUILDING IS OCCUPIED
/-7.5
NO. OF DAYS PER WEEK
/-5

APPROX. RESPONSE FACTOR FOR BUILDING
/-6

TOTAL SUM OF AREAS X U-VALUES (W/DEGC)
/-6545

WOULD YOU LIKE A LIST OF FUELS ?
/-YES
```

NO.	FUEL TYPE	BASIC UNIT	HEAT CONTENT (KWH/BASIC UNIT)	UTILISATION EFFICIENCY (%)
1	ELECTRICITY(STANDARD)	KWH	1.0	100
2	ELECTRICITY(OFF-PEAK)	KWH	1.0	100
3	GAS(NATURAL)	THERM	29.3	60
4	SOLID FUEL(COAL)	50KGS	418.9	55
5	SOLID FUEL(SMOKELESS)	50KGS	429.9	55
6	SOLID FUEL(COKE)	50KGS	429.9	55
7	FUEL OIL (35S)	L	10.6	60
8	FUEL OIL (28S)	L	10.2	60

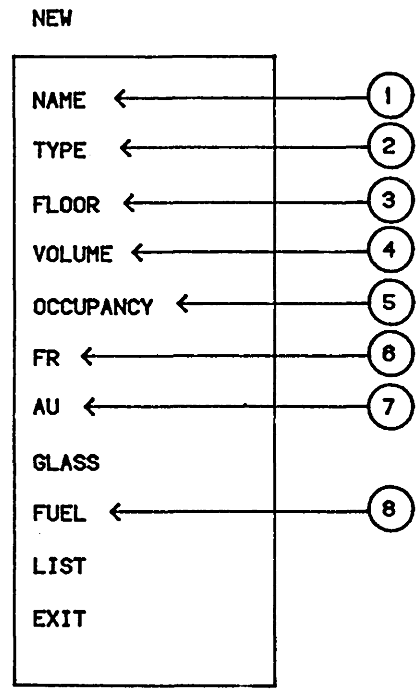


FIGURE 4.13

Describing High Green Comprehensive School (1)

NOTES

Commands may be chosen in any order. The circled numbers indicate the order of choice

The user may enter an alternative fuel type by supplying its name, unit, heat content and utilisation efficiency.

```
ARE ANY OF THE FUELS ON FILE SUITABLE ?
/-YES
FUEL NO.
/-3

IS METER READING FOR:
1   SPACE HEATING ALONE
2   SH + HOT WATER
3   SH + COOKING
4   SH + HW + COOKING
/-2

HOW MANY DIFFERENT GLAZING ORIENTATIONS ?
/-7

         ORIENTATION 1
         -------------
AREA OF GLASS (M^2)
/-103
ORIENTATION AND INCLINATION (DEG.)
/-20 90

         ORIENTATION 2
         -------------
AREA OF GLASS (M^2)
/-37
ORIENTATION AND INCLINATION (DEG.)
/-110 90

         ORIENTATION 3
         -------------
AREA OF GLASS (M^2)
/-101
ORIENTATION AND INCLINATION (DEG.)
/-160 90

         ORIENTATION 4
         -------------
AREA OF GLASS (M^2)
/-72
ORIENTATION AND INCLINATION (DEG.)
/-70 90
```

```
NEW
+-----------+
| NAME      |
| TYPE      |
| FLOOR     |
| VOLUME    |
| OCCUPANCY |
| FR        |
| AU        |
| GLASS  <--+---- (1)
| FUEL      |
| LIST      |
| EXIT      |
+-----------+
```

FIGURE 4.14

Describing High Green Comprehensive School (2)

```
        ORIENTATION 5
        -------------
AREA OF GLASS (M^2)
/-20
ORIENTATION AND INCLINATION (DEG.)
/-20 45

        ORIENTATION 6
        -------------
AREA OF GLASS (M^2)
/-20
ORIENTATION AND INCLINATION (DEG.)
/-110 45

        ORIENTATION 7
        -------------
AREA OF GLASS (M^2)
/-20
ORIENTATION AND INCLINATION (DEG.)
/--70 45
```

```
NEW

NAME
TYPE
FLOOR
VOLUME
OCCUPANCY
FR
AU
GLASS
FUEL
LIST
EXIT
```

FIGURE 4.15

Describing High Green Comprehensive School (3)

```
ED100  HIGH GREEN COMPREHENSIVE
--------------------------------
TYPE 1

FLOOR AREA                  4300.0 M^2
VOLUME                     11925.0 M^3
RESPONSE FACTOR                6.0
SUM OF AREAS X U-VALUES     6545.0 W/DEGC

GLAZING DETAILS
---------------
ORIENTATION    INCLINATION    AREA OF GLASS
    20.0           90.0           103.0
   110.0           90.0            37.0
  -160.0           90.0           101.0
   -70.0           90.0            72.0
    20.0           45.0            20.0
   110.0           45.0            20.0
   -70.0           45.0            20.0

OCCUPANCY
---------
NO. OF OCCUPANTS    450
AV. OCCUPANCY       7.5 HRS PER DAY
                    5.0 DAYS PER WEEK

FUEL DETAILS
------------
FUEL TYPE:  GAS(NATURAL)
UNIT:       THERM
HEAT CONTENT 29.307 KWH PER THERM
UTILISATION EFFICIENCY  60.0 %

METER READING INCLUDES SH + HOT WATER


O.K. TO ADD BUILDING TO FILE ? (YES/NO)
/-YES
```

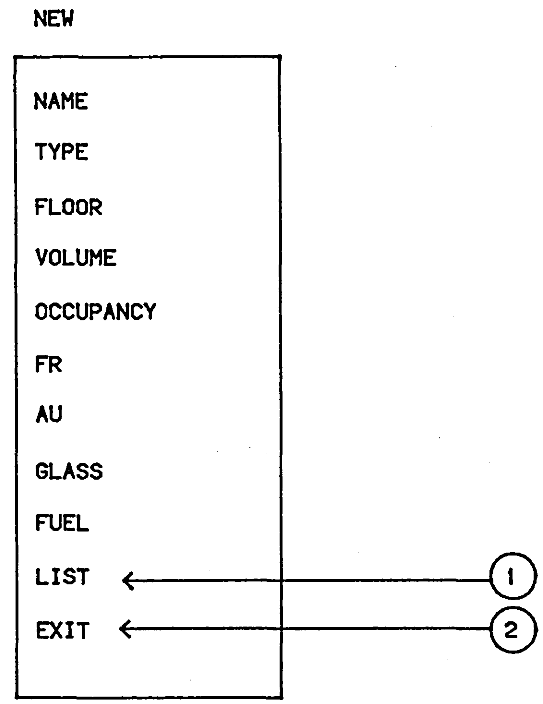
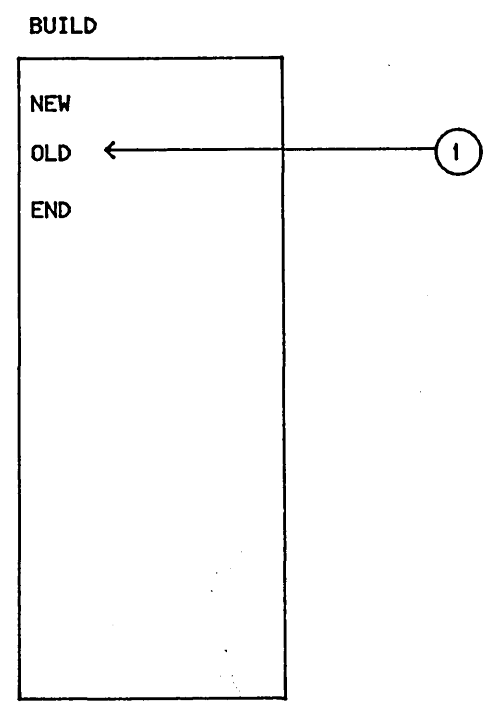


FIGURE 4.16

Describing High Green Comprehensive School (4)



NOTES

To operate on a building which already exists on the database the OLD command is chosen.

FIGURE 4.17

The BUILD Menu

```
GIVE BUILDING CODE
OR FIRST SIX LETTERS OF BUILDING NAME
/-GREEN
WHICH VERSION OF THIS BUILDING ? (1-10)
/-1

BUILDING FOUND : GREEN OAK VIEW O.P.H.
CODE           : FCS100
DATES VALID    : 1/1980 -

CONFIRM CORRECT BUILDING (YES/NO)
/-YES


FROM WHAT DATE DOES THE CHANGE APPLY ?
GIVE MONTH FOLLOWED BY YEAR (E.G. 3 81)
/-10 81
```

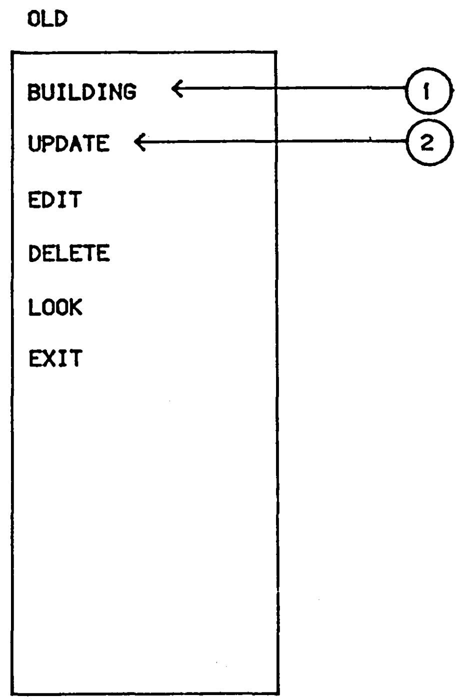


FIGURE 4.18

The OLD Menu

```
FCS100 GREEN OAK VIEW O.P.H.
----------------------------
TYPE 2

FLOOR AREA                1560.0 M^2
VOLUME                    3900.0 M^3
RESPONSE FACTOR              6.0
SUM OF AREAS X U-VALUES   3114.0 W/DEGC

GLAZING DETAILS
---------------
ORIENTATION    INCLINATION    AREA OF GLASS
   -45.0           90.0            80.0
    45.0           90.0            44.0
   135.0           90.0            58.0
  -135.0           90.0            24.0

OCCUPANCY
---------
NO. OF OCCUPANTS     41
AV. OCCUPANCY      24.0 HRS PER DAY
                    7.0 DAYS PER WEEK

FUEL DETAILS
------------
FUEL TYPE:  GAS(NATURAL)
UNIT:       THERM
HEAT CONTENT 29.307 KWH PER THERM
UTILISATION EFFICIENCY  60.0 %

METER READING INCLUDES SH + HW + COOKING


TOTAL SUM OF AREAS X U-VALUES (W/DEGC)
/-2377


O.K. TO ADD BUILDING TO FILE ? (YES/NO)
/-YES
```

```
UPDATE/EDIT

NAME
TYPE
FLOOR
VOLUME
OCCUPANCY
FR
AU     <---- 2
GLASS
FUEL
LIST   <---- 1
EXIT   <---- 3
```

FIGURE 4.19

Describing the Cavity Insulation of Green Oak View O.P.H.

NOTES

Existing details of the building are read in. The user changes the value held for the fabric heat loss using the AU command.

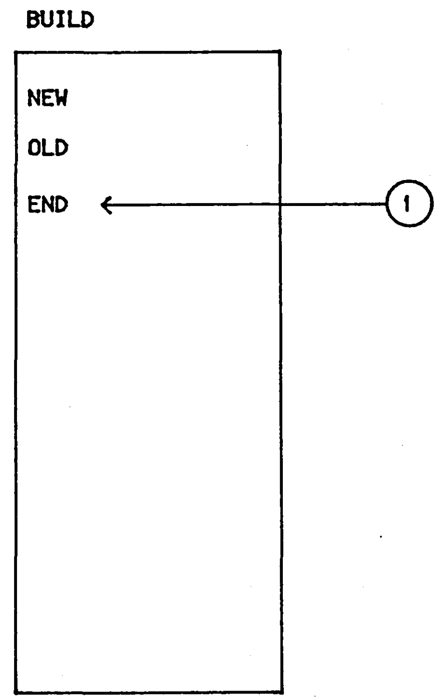


FIGURE 4.20

Terminating the Run of Program BUILD

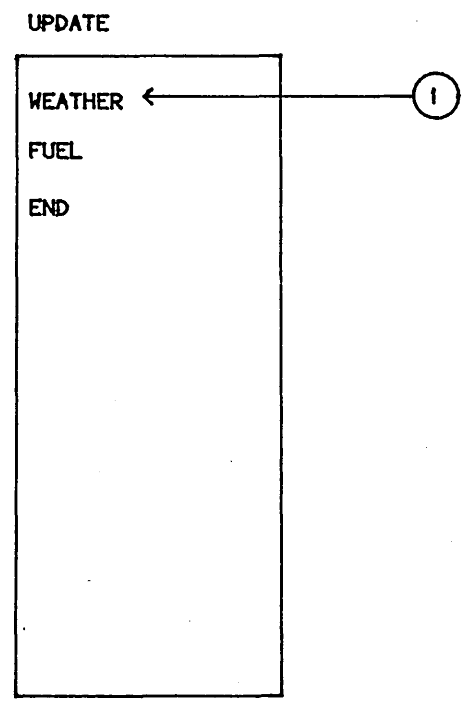


FIGURE 4.21

First Menu of Program UPDATE

```
GIVE MONTH NUMBER (1-12)
/-4

WHICH YEAR ?
/-1984

MONTH IS APRIL
30 DAYS

DAY 1
------
GIVE TMAX FOLLOWED BY TMIN
/-6.2 -0.4
DAY 2
------
/-9.7 -0.2
DAY 3
------
/-8.6 -2.6
DAY 4
------
/-9.2 -0.7
DAY 5
------
/-9.7 -2.2
DAY 6
------
6.8 3.5

DAY 7
------
/-8.3 2.7
DAY 8
------
/-10.1 4.2
DAY 9
------
/-11.0 4.7
DAY 10
-------
/-9.9 1.8
```

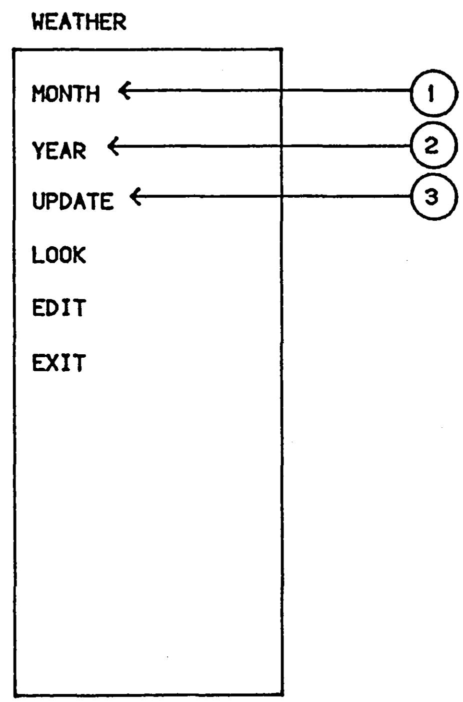


FIGURE 4.22

Input of Weather Data for April 1984 (1)

```
DAY 11
-------
/-10.0 6.7
DAY 12
-------
/-11.8 1.8
DAY 13
-------
/-11.9 5.0
DAY 14
-------
/-10.1 3.9
DAY 15
-------
/-10.1 3.0
DAY 16
-------
/-10.6 3.1
DAY 17
-------
/-12.0 2.2
DAY 18
-------
/-14.1 4.5
DAY 19
-------
/-15.6 7.8
DAY 20
-------
/-18.0 10.1
DAY 21
-------
/-21.1 9.8
DAY 22
-------
/-13.7 8.7
DAY 23
-------
/-17.2 2.4
```

```
DAY 24
-------
/-18.8 0.1
DAY 25
-------
/-20.7 3.0
DAY 26
-------
/-20.1 3.4
DAY 27
-------
/-18.5 6.4
DAY 28
-------
/-17.6 2.9
DAY 29
-------
/-15.2 4.7
DAY 30
-------
/-16.8 3.6

TOTAL SUNSHINE HOURS ?
/-205.7
```

FIGURE 4.23

Input of Weather Data for April 1984 (2)

APRIL 1984

DAY	TMAX (DEGC)	TMIN (DEGC)
1	6.1	-0.4
2	9.7	-0.2
3	8.6	-2.6
4	9.2	-0.7
5	9.7	-2.2
6	6.8	3.5
7	8.3	2.7
8	10.1	4.2
9	11.0	4.7
10	9.9	1.8
11	10.0	6.7
12	11.8	1.8
13	11.9	5.0
14	16.1	3.9
15	10.1	3.0
16	10.6	3.1
17	12.0	2.2
18	14.1	4.5
19	15.6	7.8
20	18.0	10.1
21	21.1	9.8
22	13.7	8.7
23	17.2	2.4
24	18.8	0.1
25	20.7	3.0
26	20.1	3.4
27	18.5	6.4
28	17.6	2.9
29	15.2	4.7
30	16.8	3.6

TOTAL SUNSHINE HRS. = 205.7

IS ALL THE INFORMATION CORRECT ?
/-YES

WEATHER

MONTH
YEAR
UPDATE
LOOK
EDIT
EXIT ← 1

FIGURE 4.24

Input of Weather Data for April 1984 (3)

NOTES

The user is given the oppurtunity to correct any of the data before it is written to the disk file.

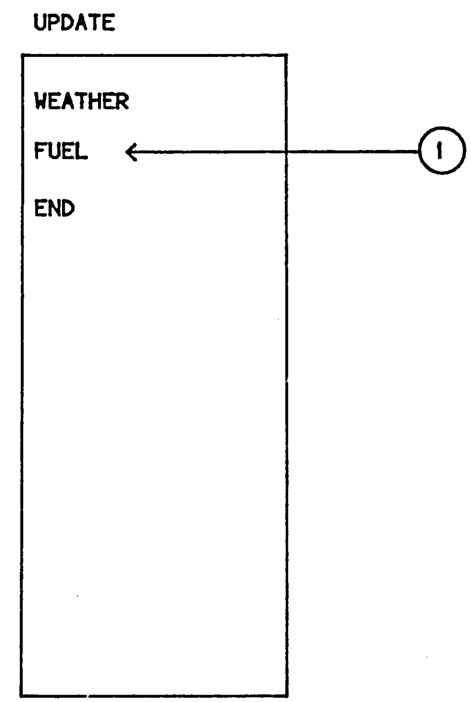


FIGURE 4.25

First Menu of Program UPDATE

```
YEAR ?
/-1983
MONTH ?
/-11

INPUT CONSUMPTIONS FOR 11/83
ANSWER 0 IF UNKNOWN

BOWLS PAVILION HILLSBOROUGH PARK
(KWH)
/-456
BRANCH LIBRARY, HILLSBOROUGH
(THERM)
/-1459
DOBCROFT 1ST & MIDDLE SCHOOLS
(THERM)
/-2365
GREEN OAK VIEW O.P.H.
(THERM)
/-1895
HAWKHILLS O.P.H.
(THERM)
/-1089
HIGH GREEN COMPREHENSIVE
(THERM)
/-2314
HILLSBOROUGH F&M
(THERM)
/-1360
HOLME LANE DEPOT
(THERM)
/-378
MALIN BRIDGE J&I
(THERM)
/-1578
MEADE HOUSE
(THERM)
/-459
MESS ROOM HILLSBOROUGH PARK
(THERM)
/-650C
MYERS GROVE
(LITRE)
/-25600
```

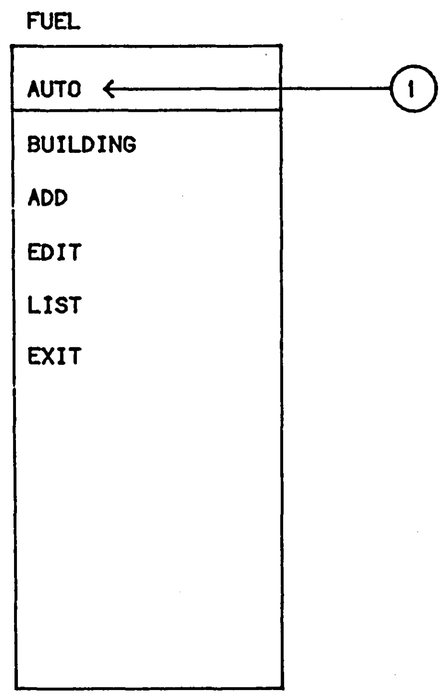


FIGURE 4.26

Entering Fuel Consumptions for a Specific Month

NOTES

If a meter reading is unknown then the user enters a '0'.

Comment characters may be appended to the reading e.g. 1200C indicates a corrected reading, 934E an estimated reading.

```
PRIMROSE VIEW
(THERM)
/-0
ROSCOE COURT
(THERM)
/-1236
SEVENFIELDS O.P.H.
(THERM)
/-1400
SHOOTERS GROVE F&M
(LITRE)
/-5000
SPORTS PAVILION HILLSBOROUGH PARK
(KWH)
/-159
THAT'S THE LOT !

GIVE BUILDING CODE
OR FIRST SIX LETTERS OF BUILDING NAME
/-GREEN

WHICH YEAR ?
/-1984

ADDING TO :
GREEN OAK VIEW O.P.H.

1984
----

JAN 3538 THERM
FEB 3587 THERM
MAR (THERM) ?
/-2654
APR (THERM) ?
/-2140
MAY (THERM) ?
/-1560
JUN (THERM) ?
/-1150
JUL (THERM) ?
/-S
```

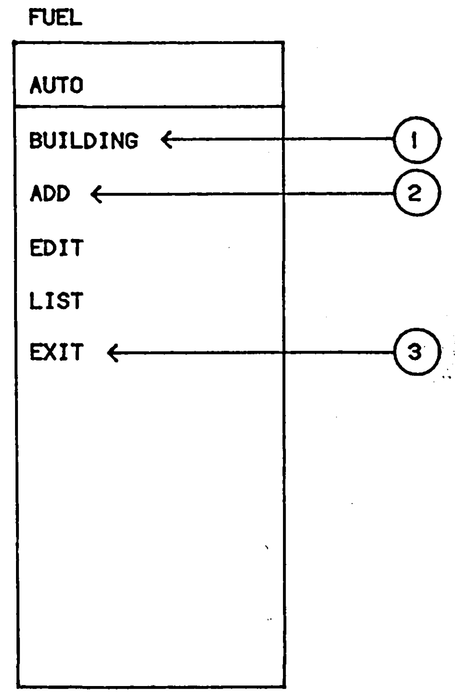


FIGURE 4.27

Entering Fuel Consumptions for a Specific Building

NOTES

Consumptions for Green Oak View have already been entered for Jan. and Feb. 1984.
The user enters figures for March to June and ends the ADD command by entering an 'S' (stop) for July.

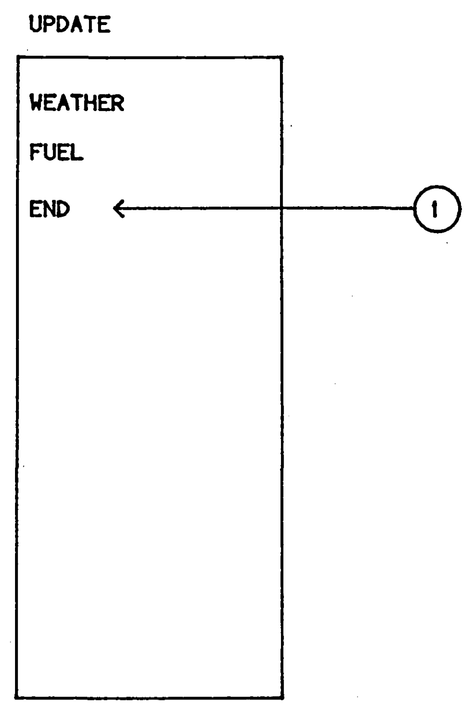


FIGURE 4.28

Terminating the Run of Program UPDATE

APRIL 1982

BUILDING	FLOOR AREA	PREDICTED CONSUMPTION	ACTUAL CONS.	% OVER PRED.	FUEL UNITS
BOWLS PAVILION HILLSBOROUGH	182	6633(3644)	0 (0)	-100	KWH
BRANCH LIBRARY HILLSBOROUGH	715	805 (112)	1865 (260)	131	THERM
DOBCROFT 1ST&MIDDLE SCHOOLS	2590	1673 (64)	0 (0)	-100	THERM
GREEN OAK VIEW O.P.H.	1560	1753 (112)	2579 (165)	47	THERM
HAWKHILLS O.P.H.	1326	2337 (176)	2461 (185)	5	THERM
HIGH GREEN COMPREHENSIVE	4300	1604 (37)	0 (0)	-100	THERM
HILLSBOROUGH F&M	2836	2686 (94)	2080 (73)	-22	THERM
HOLME LANE DEPOT	443	660 (148)	2039 (460)	208	THERM
MALIN BRIDGE J&I	1742	1701 (97)	2450 (141)	41	THERM
MEADE HOUSE	448	473 (105)	0 (0)	-100	THERM
MESS ROOM HILLSBOROUGH PARK	43	312 (725)	196 (455)	-37	KWH
MYERS GROVE SCHOOL	10321	27008 (261)	38500 (373)	42	LITRE
PARK VIEW LODGE	1630	2479 (152)	0 (0)	-100	THERM
ROSCOE COURT	2285	3479 (164)	0 (0)	-100	THERM
SEVENFIELDS O.P.H.	1464	2244 (153)	2246 (153)	0	THERM
SHOOTERS GROVE F&M	2412	4999 (207)	5000 (207)	0	LITRE
SPORTS PAVILION HILLSBORO'	192	5141(2678)	0 (0)	0	KWH
STANNINGTON COLLEGE	9695	6815 (70)	34800 (359)	410	LITRE

FIGURE 4.29

Output from Program ENMAN1 for April 1982

NOTES

The figures shown in brackets represent the consumptions per 100 m2 floor area.

```
BUILDING CODE OR FIRST SIX
LETTERS OF BUILDING NAME
/-HAWKHI

START MONTH
/-4
YEAR ?
/-81

BUILDING CODE OR FIRST SIX
LETTERS OF BUILDING NAME
/-MYERS

START MONTH
/-6
YEAR ?
/-80

HOW MANY MONTHS DATA ? (MAX. 36)
/-36

BUILDING CODE OR FIRST SIX
LETTERS OF BUILDING NAME
/-SHOOTE
```

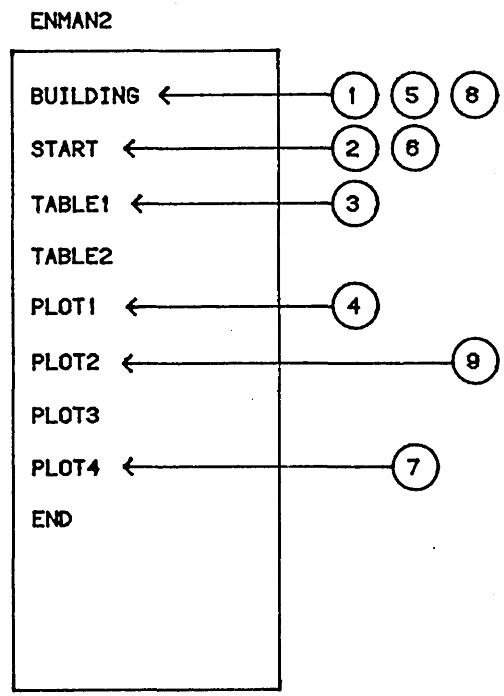


FIGURE 4.30

Using Commands from Program ENMAN2

NOTES

Output from these commands is shown in Figures 4.31 to 4.34

HAWKHILLS OPH

YEAR 1981

MONTH	AV.INT. TEMP	AV.DAILY SOLAR GAIN	TOTAL DAILY GAIN	D.DAY BASE	D.DAYS	ENERGY KWH	THERMS
APRIL	21.0	222.2	381.0	17.9	313.	48860	2779
MAY	21.0	271.8	430.6	17.5	186.	33544	1908
JUNE	21.0	296.6	455.4	17.3	117.	24783	1409
JULY	21.0	295.8	454.6	17.3	68.	19139	1088
AUGUST	21.0	283.8	442.6	17.4	67.	18939	1077
SEPTEMBER	21.0	254.2	413.0	17.6	96.	22170	1261
OCTOBER	21.0	165.1	323.9	18.4	311.	48927	2783
NOVEMBER	21.0	70.4	229.2	19.1	343.	52551	2989
DECEMBER	21.0	52.8	211.6	19.3	597.	83941	4774
JANUARY	21.0	69.7	228.5	19.1	507.	72925	4148
FEBRUARY	21.0	81.6	240.4	19.0	403.	59184	3366
MARCH	21.0	208.2	367.0	18.0	365.	55572	3161

FIGURE 4.31 Output using the TABLE1 command

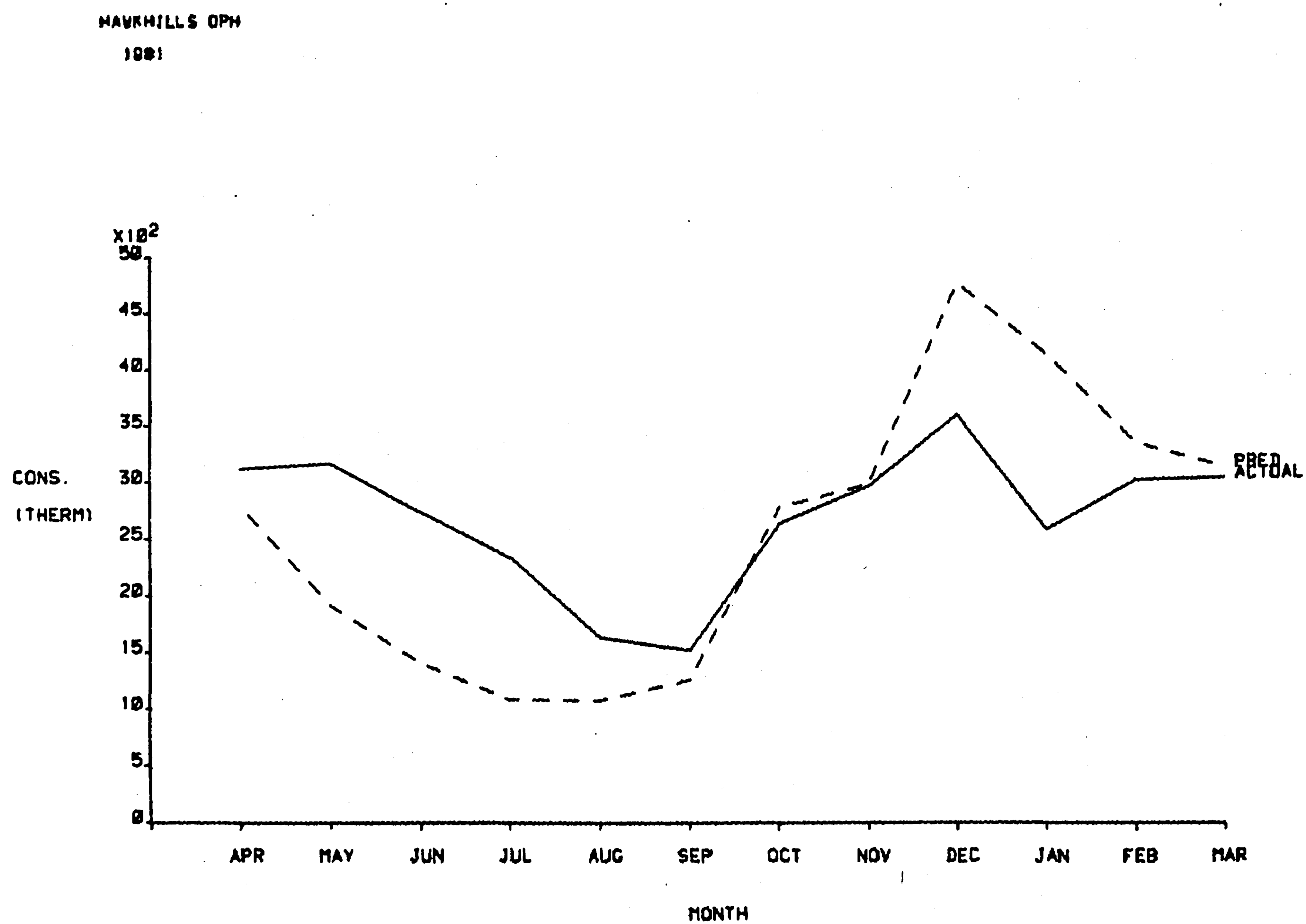


FIGURE 4.32 Output using the PLOT1 command

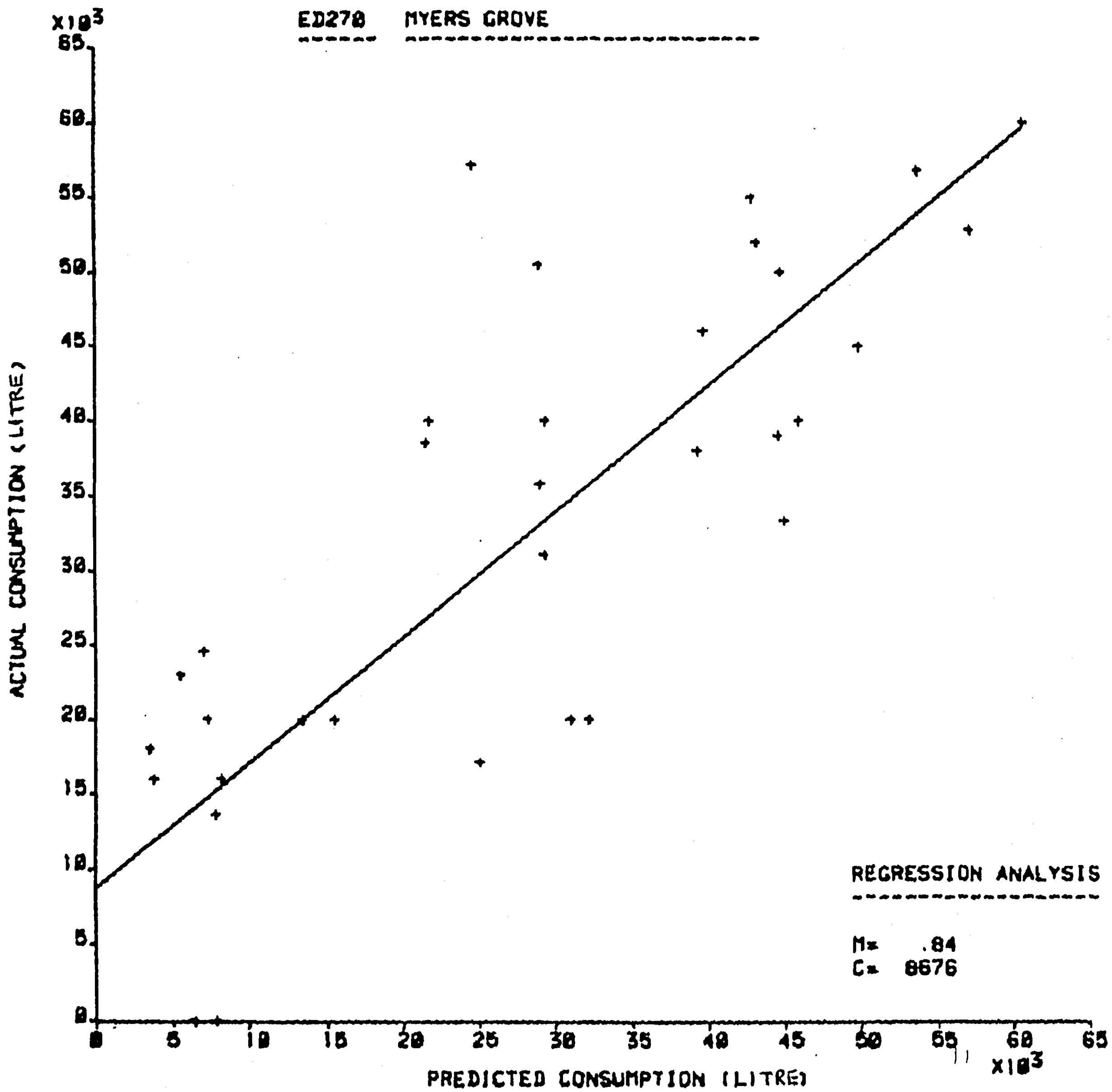


FIGURE 4.33 Output using the PLOT4 command

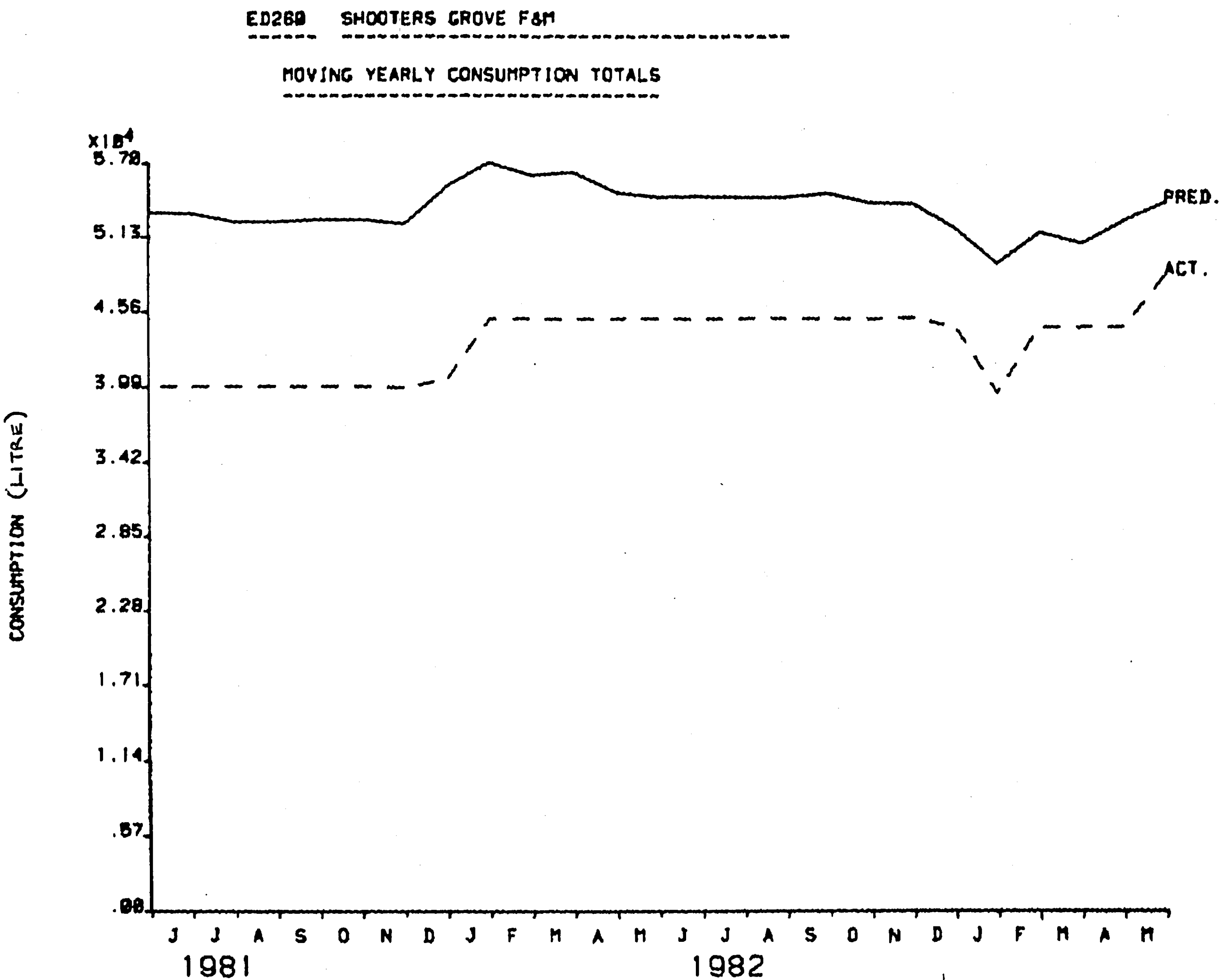


FIGURE 4.34 Output using the PLOT2 command

5.1 INTRODUCTION

The first testing of the model described in Chapter 3 was actually carried out well before the complete implementation of the ENMAN programs. It was felt that it would be a mistake to progress too far with a complete working system of computer programs before the predictions of the energy model had been, in some way, compared with the actual energy consumption of real buildings.

The model was initially developed to a stage where predictions of energy consumption could be made by a combination of manual calculations and short computer programs. The first sections of the model to be computerised were the solar gain and degree-day calculations as these would have been extremely time consuming to perform manually. Of course, both these programs were initially checked against manual calculation to make sure they were reliable.

For the initial verification of the mathematical model four buildings were chosen as a representative sample of local authority controlled buildings :-

(i) Primrose View Old Peoples' Home - this is a mainly two-storey building of traditional brick-cavity-block construction built in the late 'sixties. The building accomodates 41 old people together with resident and non-resident staff and is heated continuously.

(ii) Green Oak View O.P.H. - this building is of similar construction, size and age to Primrose View but has a greater external fabric area because of a larger proportion of single-storey accomodation. The external walls were cavity insulated in October 1981.

(iii) Dobcroft First and Middle Schools - this school is of typical mid-'sixties system-built construction. The building is mainly composed of a steel frame with infill panels and large areas of glazing.

(iv) High Green Comprehensive School - this school was built in 1974 and represents a much more energy-efficient design than Dobcroft. Glazing areas are small and the structure has a high thermal capacity due to the use of a heavy concrete construction. The building is known to be a very conservative user of energy compared to other educational buildings in Sheffield.

These buildings were selected because they cover a broad cross-section of Council managed property in terms of both construction and usage. The old peoples' homes are heated continuously to an appropriate degree of thermal comfort while the schools are heated during the daytime only to a design temperature of 19°C (66°F).

The results from the analysis of these four buildings allowed the model to be assessed and modifications were made to the model where they could be justified.

Following this work ENMAN was progressed to its first, fully integrated system of computer programs. The programs were then available, as the complete package described in Chapter 4, for use by members of the City Council's Energy Control Section. A further sixteen buildings were then analysed in a second stage of comparison. These buildings were all located within the 'Hillsborough Energy Action Area'.

The Action Area was a scheme devised to investigate detailed energy conservation measures and to monitor the benefits of these measures for a small number of buildings with a view to determining a city-wide energy policy. Of course, one of the first steps to establishing a set of cost-effective energy conservation measures is to determine which buildings are excessive users of energy : it was for this purpose that ENMAN was used during the project. ENMAN will be used in the future monitoring phase to discover whether the expected benefits of energy conservation work are actually achieved.

Section 5.2 describes the initial results obtained for the first set of four buildings and shows how these results were used in the verification and modification of the mathematical model.

Sections 5.3 and 5.4 take two buildings, Green Oak View Old Peoples' Home and Hillsborough First and Middle School, and describe in detail the results obtained using the ENMAN programs.

Section 5.5 summarises the comparison between calculated fuel requirement and actual fuel consumption for all the buildings held on the ENMAN system .

5.2 INITIAL VERIFICATION OF THE MODEL

Description of Graphical Results

Figures 5.1 to 5.4 show a graphical comparison between actual fuel consumption and calculated fuel requirements for the first four 'test' buildings. For each month (or quarter in the case of Primrose View Old Peoples' Home) the actual consumption is plotted aginst the prediction. Figures 5.1 and 5.2 show the effect on the predicted consumptions of using different ventilation rates and design temperatures.

If the buildings' performance was exactly as predicted by the model then all the points would lie on a straight line (shown dotted in the figures) with a gradient of unity passing through the origin.

Parameters likely to affect the gradient of the best straight line plotted through the points are the differences between the assumed and actual values of ventilation rate, internal temperature, fabric heat conductance and incidental gains. An intercept off the origin would tend to indicate some constant trend, independent of climate, such as the difference between actual and assumed values of hot water consumption or cooking consumption (i.e. loads other than space heating). The following subsections will attempt to explain the discrepancies between predicted and actual energy consumption and to justify the choice of ventilation rates , internal temperatures and levels of incidental heat gain used in the model.

Effects of Ventilation Rate and Design Internal Temperature

Assuming that physical parameters of the building such as its floor area, volume and fabric heat loss are not subject to large errors, ventilation rate and internal temperature are the two parameters which have the greatest effect on the calculated fuel requirements. This is clearly shown in Figures 5.1 and 5.2.

Referring to Figure 5.1, the predictions for High Green Comprehensive School based on a ventilation rate of 1 air change per hour show good correlation with actual fuel consumptions. Those based on 2 ac/h ,with no other parameters altered,show a significantly poorer correlation. Superficially it may appear that the choice of 1 ac/h is about correct for this school. However, the actual ventilation rate may be 2 ac/h while other parameters may have been inaccurately specified. For example, in Figure 5.2 it can be observed that a difference of 2°C in the internal design temperature can have approximately the same effect as a doubling of ventilation rate from ½ to 1 ac/h.

A similar problem exists with all the parameters used in the model - it is not possible to determine whether a difference between predicted and actual consumption is due to an incorrect parameter value, several incorrect values or indeed a fault in the model. One way around this problem would be to constantly monitor internal temperatures, ventilation, occupancy patterns, cooking and hot water usage etc., in this way it would only be the model that was being tested. Unfortunately such monitoring is beyond the scope of this project.

To a limited extent however, some adjustment was possible during the testing of the model. Figure 5.2 shows results for Green Oak View Old Peoples' Home using two alternative temperatures of 21 and 23°C. 21°C was the internal design temperature while 23°C was actually measured in nearly all areas of the building during a visit in the winter of 1982. The use of 23°C in the model actually gave a better correlation of results for both Green Oak View and Primrose View (Figure 5.4). Nevertheless, for any use other than checking of the model, 21°C was used as a design temperature so that an excessive temperature level could be spotlighted.

For verification purposes it was necessary to employ temperature and ventilation rates which were considered to be a true reflection of actual conditions. As explained in Section 3.4 however, the values used in subsequent monitoring of performance are those thought to be realistic for the use to which a building is being put.

Effects of Incidental Heat Gains

The error equations of Appendix III show that significant errors in the assessment of incidental heat gains can have a small effect on the prediction of fuel requirement. However the calculations were based on a typical winter's month for an arbitrary building.

It was found on first testing the model that for old peoples' homes in particular (which have a high ratio of floor area to the number of occupants) that the figures used for heat gain from lighting had a great effect on the predicted energy consumption. Initially a value of 10 W/m^2 was used as stated in the CIBS Guide, but both the model and the Guide make the assumption that lighting is used for the full occupancy hours and across the complete floor area of the building. Although it was clear that lighting is used for probably 12 hours per day in communal areas and 24 hours in corridors; in the bedrooms, which constitute in general more than half the floor area of an old peoples'home, lighting might only be used for two or three hours per day. To assume a heat gain of 10W for every square metre of a home and for 24 hours per day was clearly inaccurate. A more realistic figure of 2.5 W/m^2 was eventually decided upon but this is still an arbitrary figure and is bound to vary considerably from building to building and from season to season.

With schools and other institutional buildings, artificial lighting is generally used throughout the hours of occupancy and the CIBS Guide figure can be used without adjustment.

Attempts were made to assess lighting use from electricity meter readings but it quickly became clear that so many other electrical appliances were in operation that this assessment was unreliable.

Energy Consumption During the Summer Months

In the summer months it is clear that the major proportion of energy consumption is not due to space heating but to other utilities such as hot water heating and cooking. Unfortunately, in most local authority buildings and certainly in the four buildings under test, hot water and cooking consumption are not metered separately from space heating. The model thus has to approximate the consumption of these utilities whenever they are included on the main meter. This brings an extra degree of uncertainty to the prediction process but, during the summer months, the consumption of extra utilities can be quite accurately gauged because space heating is rarely used.

As shown in Figures 5.1 and 5.3, the assumptions of the model about consumptions other than space heating seem to give good agreement between predicted and actual usage for the two schools. The two old peoples' homes (see Figures 5.2 and 5.4), however, appear to consume an excessive amount of gas in the summer months (points on the left hand side of the graphs). Because the old peoples' homes consume large quantities of hot water for bathing, laundry etc., the heating of hot water is a major factor in the overall fuel usage. A gas consumption of approximately 500 therm per month is predicted for hot water consumption in each of the two homes but is exceeded by some 1000 therm per month at Green Oak View and 850 therm per month at Primrose View (as indicated by the intercepts on the graphs).

The overall efficiency of the boilers and distribution system has been assumed to be 60 % for both space heating and hot water heating. This should be easily achievable (45) for a correctly scheduled boiler plant. However it is clear that, during the summer period, large boilers are being run purely for hot water production and therefore at reduced load. The efficincy of boilers can drop significantly at part load and this could,in part,explain the excessive gas consumption during the summer. Another explanation could be that hot water consumption may be significantly more than the 130 litres per person per day assumed by the model.

The current aim of the Authority is that the scheduling of boilers should be optimised to maximise efficiency during the summer months. Completely separate hot water boilers have been installed in many instances. To aid the identification of those boiler installations requiring attention, the model assumes the same value for summer and winter efficiency. This figure is supplied by the user during building description.

Discussion

The model has produced a good agreement between predicted and actual consumption for the two schools ; the two old peoples' homes exhibit poorer agreement. In the old peoples' homes hot water consumption represents a far greater proportion of total energy requirement and this consumption is difficult to predict. The model has used statistical averages of hot water consumption (38).

It is very difficult to determine whether the old peoples' homes are truly excessive consumers of energy or that the model is at fault. However, the excessive summer consumption had been suspected for some time, therefore it was decided to proceed with the development of ENMAN using the same model.

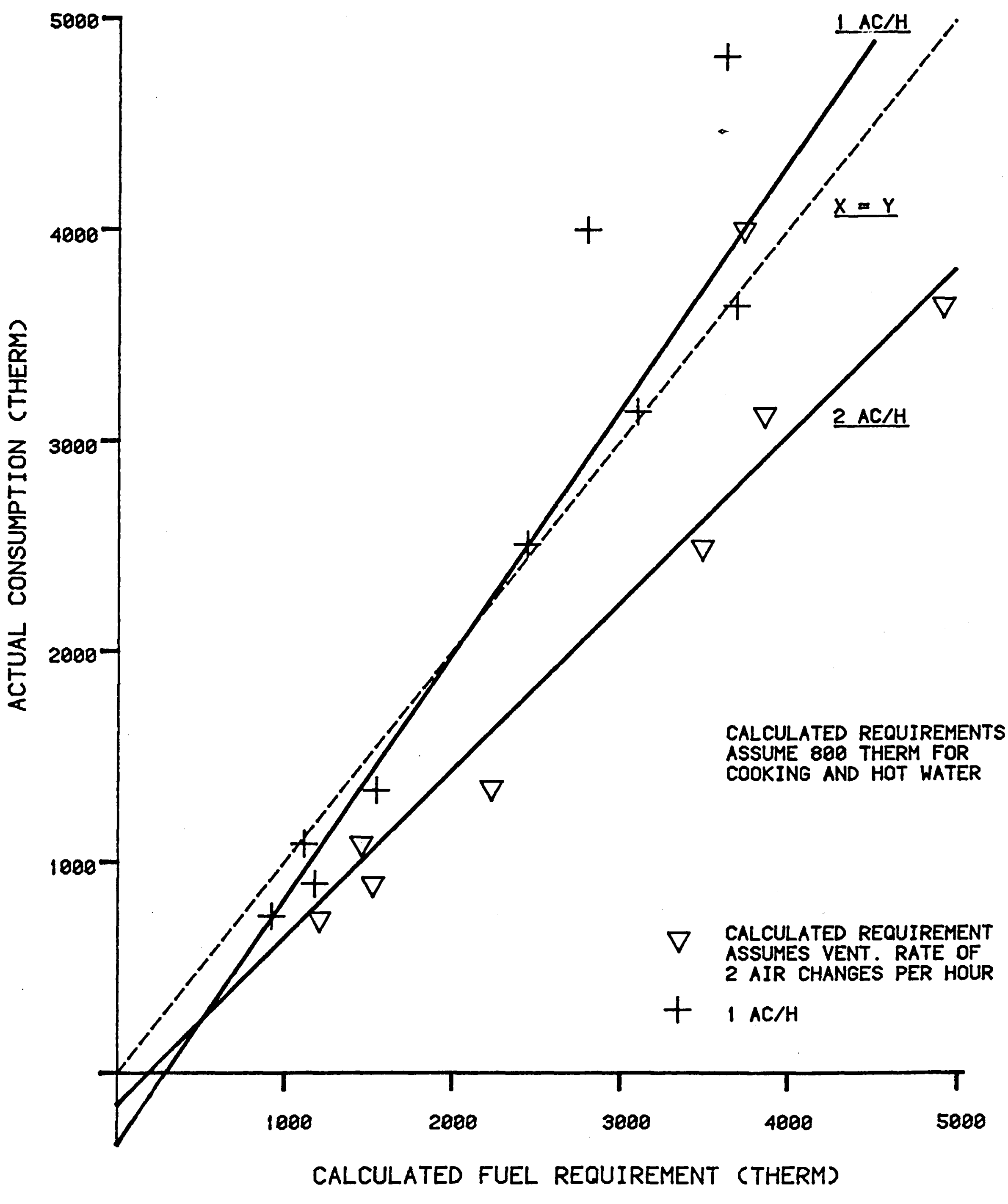


FIGURE 5.1

PLOT OF ACTUAL VERSUS CALCULATED CONSUMPTION FOR HIGH GREEN COMPREHENSIVE SCHOOL 1980/1

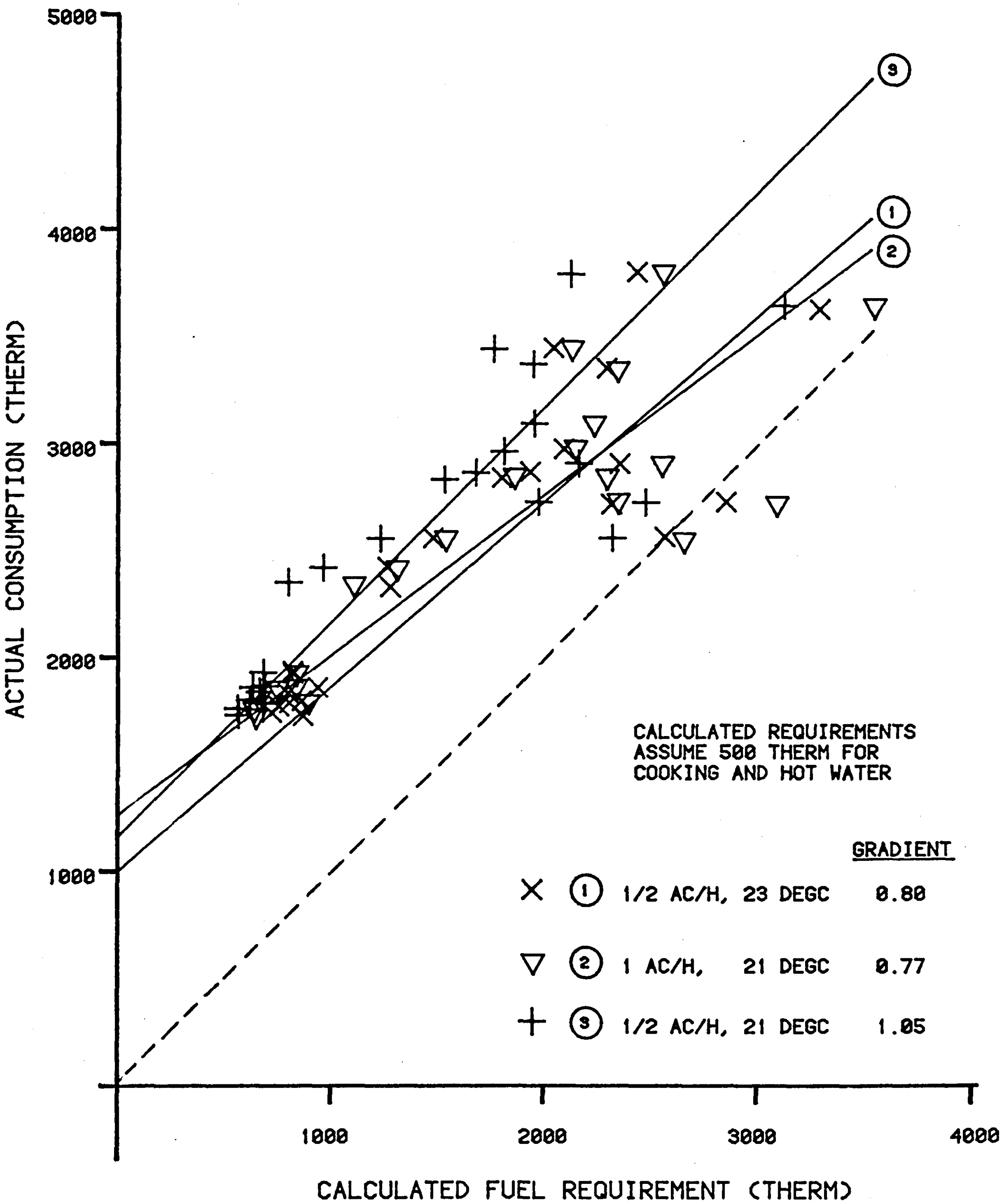


FIGURE 5.2

PLOT OF ACTUAL VERSUS CALCULATED CONSUMPTION FOR GREEN OAK VIEW OLD PEOPLES' HOME 1980/1

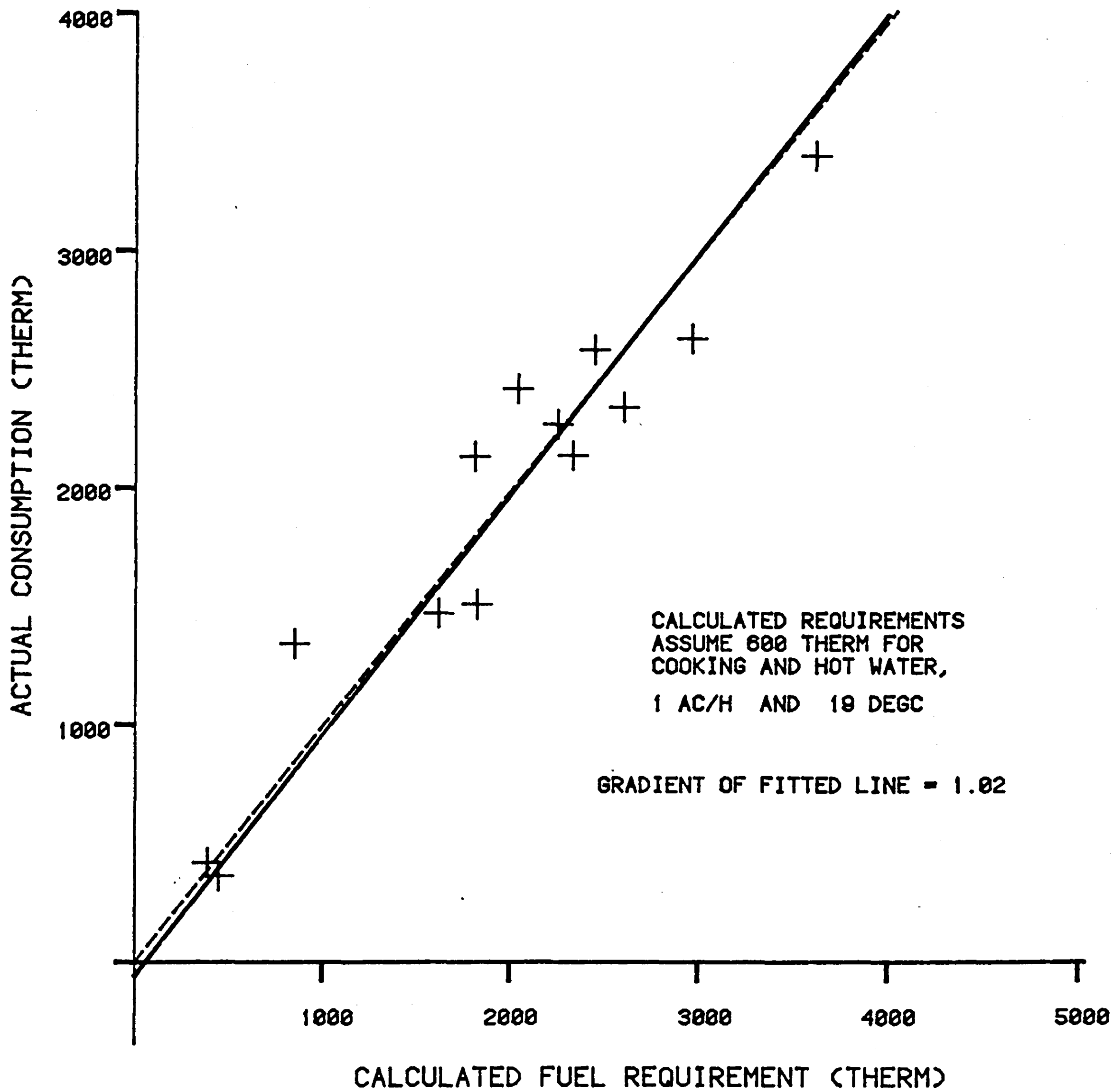


FIGURE 5.3

PLOT OF ACTUAL VERSUS CALCULATED CONSUMPTION FOR DOBCROFT FIRST & MIDDLE SCHOOL 1980/1

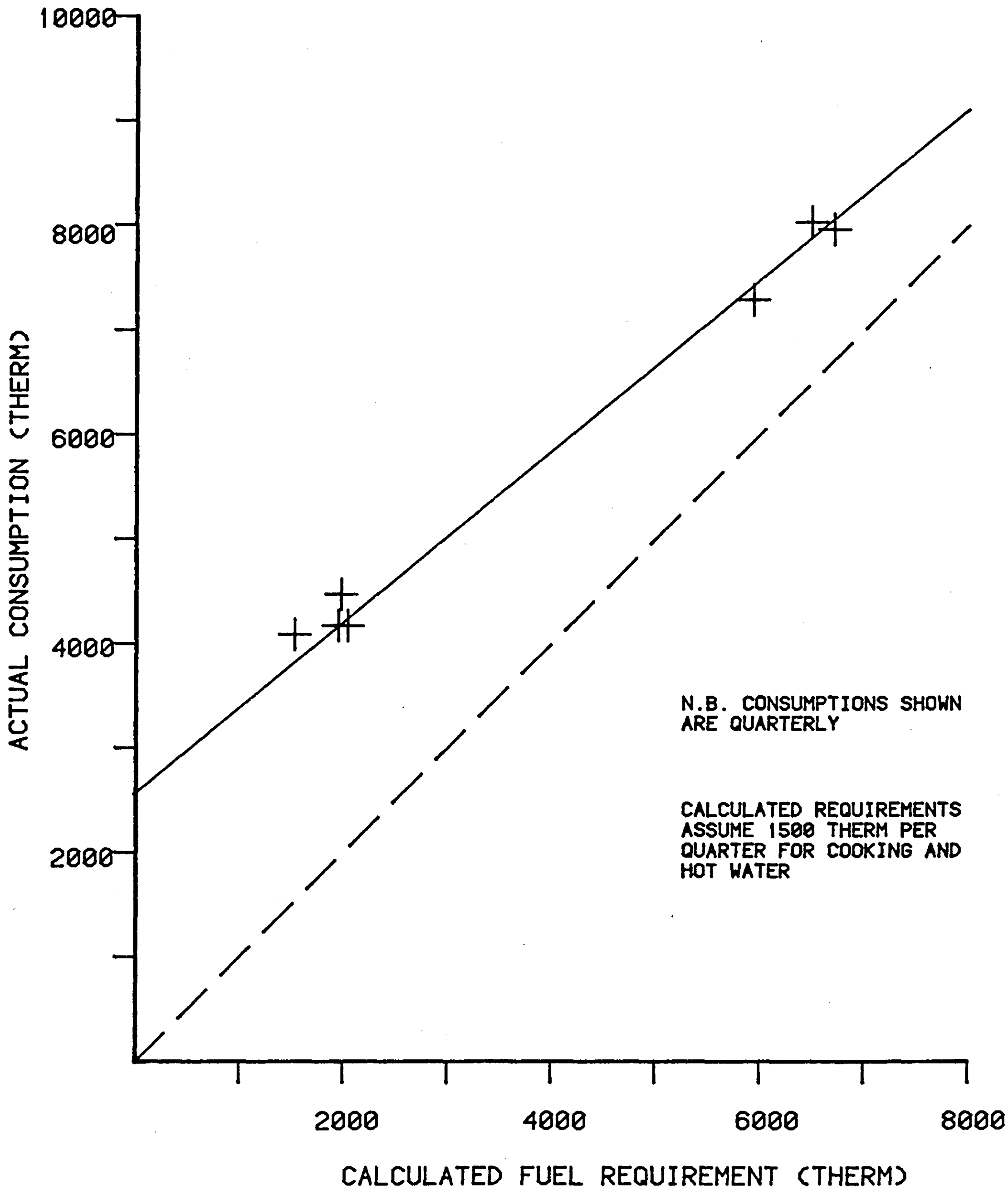


FIGURE 5.4

PLOT OF ACTUAL VERSUS CALCULATED CONSUMPTION FOR PRIMROSE VIEW OLD PEOPLES' HOME 1980/1

5.3 FIRST CASE STUDY - GREEN OAK VIEW OLD PEOPLES' HOME

Monthly Consumptions

Figure 5.5 shows the output obtained using the TABLE1 command in program ENMAN2 for 1980. Because the home is heated continuously the 24 hour average internal air temperature shown in the first column is constant and equal to the design temperature of 21 °C. In the second column the predicted average daily solar gains are shown to vary between 77 kWh in December and 319 kWh in August. The gains from people and lighting, which are given the same value each month, are added to the solar gains to give the total daily incidental heat gains shown in the third column. The degree-day base temperature shown in the fourth column is not constant throughout the year because of the variation of incidental heat gains between summer and winter. This highlights a drawback of fixed base degree-day calculations which can take no account of the variation of solar gain.

The output obtained using the PLOT1 command (Figure 5.6) shows a graphical comparison between the predictions from the final column of Figure 5.5 and the recorded values of actual fuel consumption. It can be seen that the consumptions are in better agreement during the winter than during the summer. The reasons for the apparently excessive use of fuel in summer are described in the previous Section. The boilers are intended to be sequenced in the near future with an aim of making hot water production more efficient in the summer.

Moving Yearly Consumption Totals

Figure 5.7 shows the graph obtained using the PLOT2 command for the period December 1980 to December 1982. The moving yearly totals of predicted and actual consumption follow parallel courses but, in overall terms, the building is shown to consume approximately 8000 therm or 35% more gas than its calculated fuel requirement. This discrepancy is largely accounted for by the summer overconsumption but other explanations may lie in the following factors:-

(i) temperatures of 23°C have been measured in the home, the prediction assumes 21°C.

(ii) the inner leaf of the external walls is of blockwork whose exact K-value (thermal conductivity in W/m °C) is not known. 0.4 W/m °C was assumed , being a typical value for concrete blocks used around the time of construction, and this resulted in a U-value of 1.36 W/m^2 °C being used in calculations. If the blocks were of dense concrete however the U-value may be as high as 1.8 W/m^2 °C. Use of this U-value would have resulted in the predictions being approximately 10% greater.

(iii) ventilation may have been more than the 1 air change per hour target. It was evident during visits to the home that many windows were being left open.

The building was cavity insulated in October 1981 reducing the U-value of the walls from 1.36 W/m^2 °C to 0.51 W/m^2 °C and this reduces the total fabric heat loss by some 25%. The UPDATE command in program BUILD was used to register this change so that all predictions after October 1981 are based on the insulated building.

During the winter of 1981 the consumption of the home was expected to drop because of the improved insulation. However, as shown in Figure 5.7 ,the moving yearly total of actual consumption remained steady indicating a similar level of consumption to the previous winter . Without the use of a calculation such as that made by ENMAN it would not have been possible to fully assess the success of the cavity insulation because apparently no energy is being saved. However, it can be seen from Figure 5.7 that the actual consumption does follow a parallel course to the predictions for the newly insulated building. Superimposed on the same graph are the predictions for the hypothetical uninsulated building which shows the expected level of energy consumption had the building not been insulated. Clearly illustrated is the significant climb in the predicted moving yearly total consumption caused by the exceptionally cold winter of 1981/2.

From these results the cavity insulation can claim success because the trend of energy consumption follows the insulated predictions far more closely than those for the uninsulated building. In this way ENMAN is an useful tool for assessing whether insulation simply leads to increased temperatures within a building because of poor thermostatic control or whether energy is actually being saved.

GREEN OAK VIEW OPH

YEAR 1980

MONTH	AV.INT. TEMP	AV.DAILY SOLAR GAIN	TOTAL DAILY GAIN	D.DAY BASE	D.DAYS	ENERGY KWH	THERMS
JANUARY	21.0	85.4	310.4	18.1	485.	61437	3494
FEBRUARY	21.0	91.1	316.1	18.0	366.	48199	2741
MARCH	21.0	200.5	425.5	17.0	377.	50019	2845
APRIL	21.0	312.8	537.8	15.9	202.	31093	1768
MAY	21.0	397.5	622.5	15.1	145.	25380	1443
JUNE	21.0	298.2	523.2	16.1	84.	18651	1060
JULY	21.0	306.0	531.0	16.0	72.	17626	1002
AUGUST	21.0	319.1	544.1	15.9	39.	14167	805
SEPTEMBER	21.0	296.1	521.1	16.1	56.	15618	888
OCTOBER	21.0	180.8	405.8	17.2	260.	37599	2138
NOVEMBER	21.0	87.3	312.3	18.1	345.	46312	2634
DECEMBER	21.0	76.7	301.7	18.2	383.	50619	2879

FIGURE 5.5 Output using the TABLE1 command

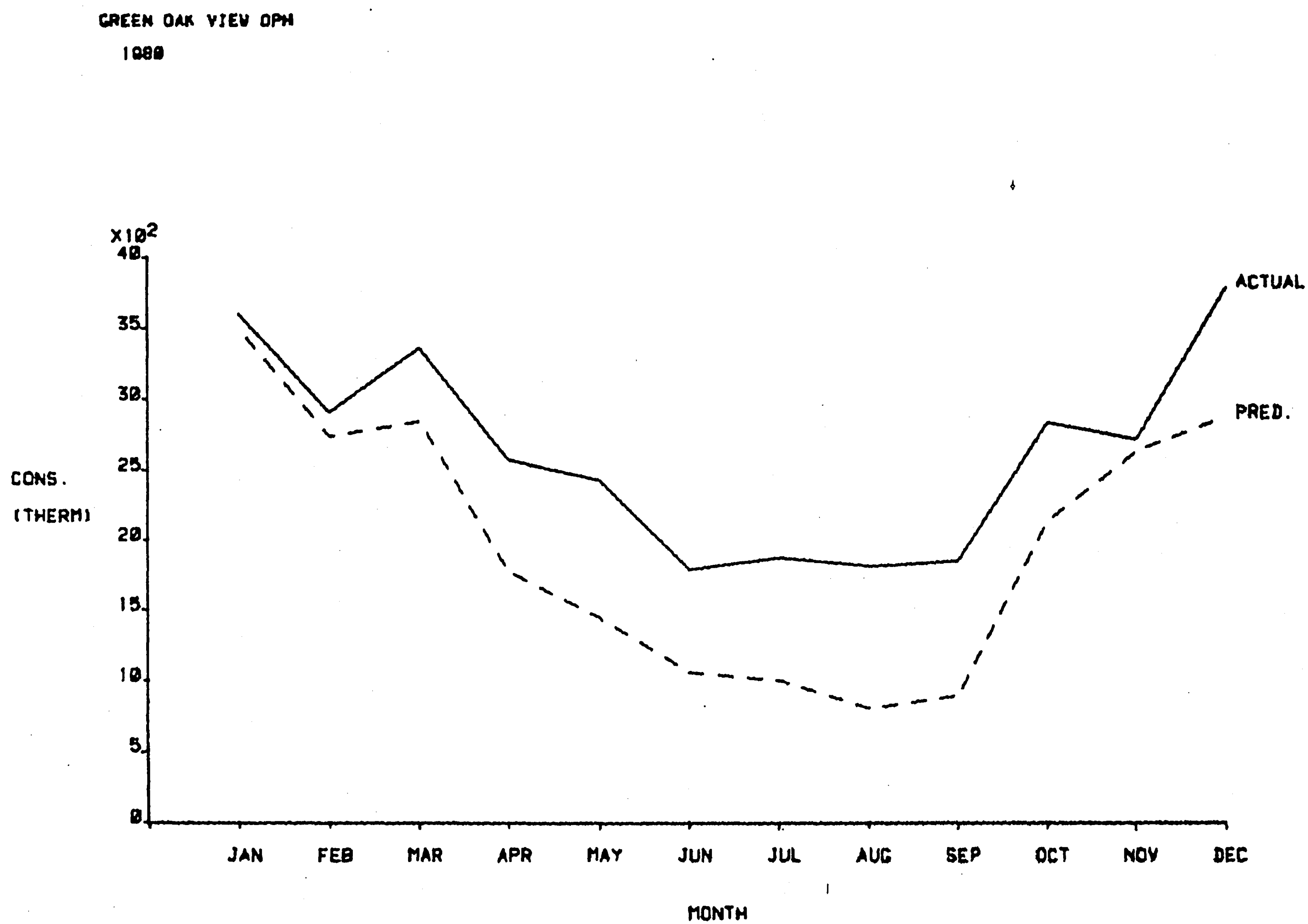


FIGURE 5.6 Output using the PLOT1 command

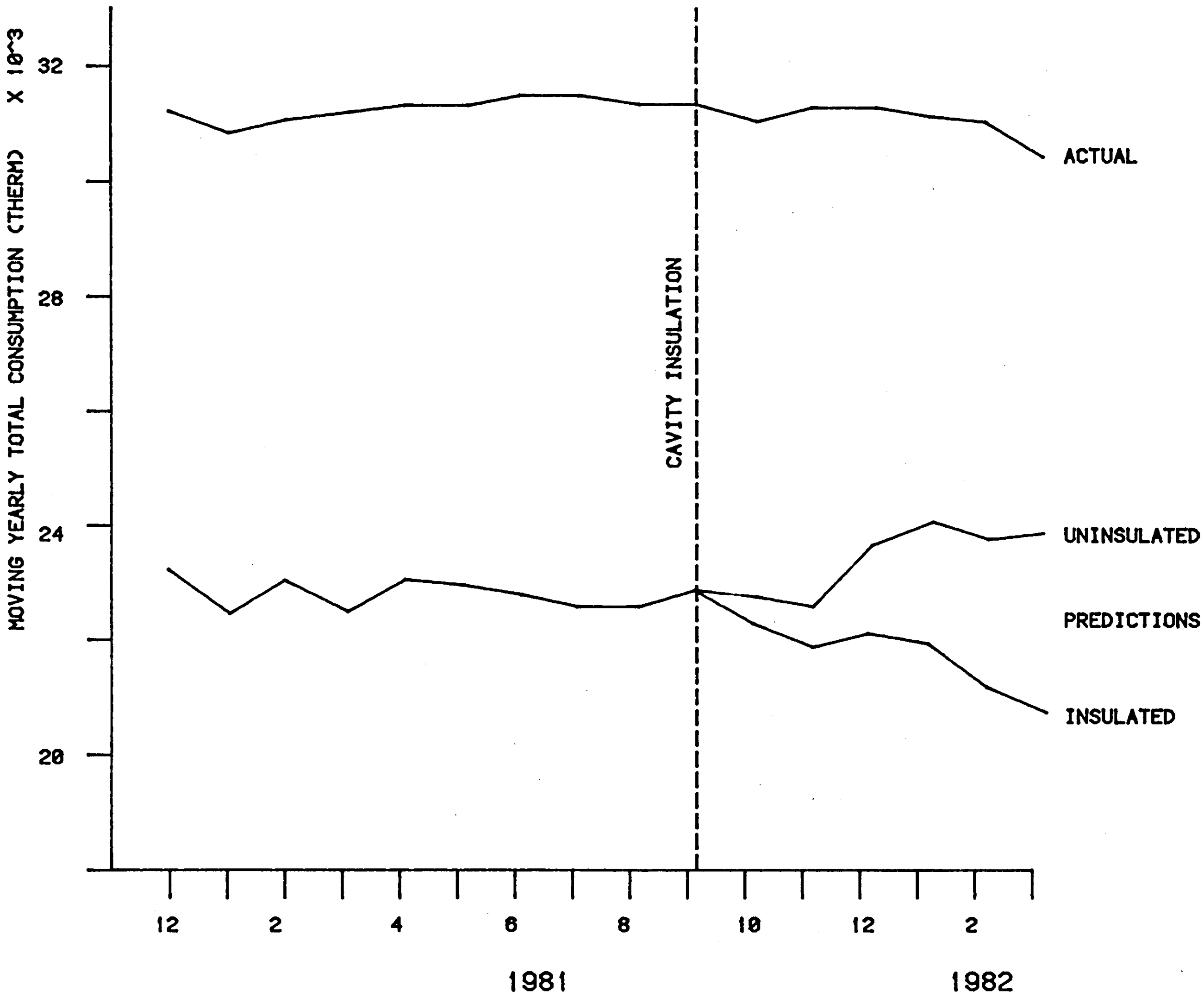


FIGURE 5.7

PLOT OF MOVING YEARLY TOTAL CONSUMPTIONS FOR GREEN OAK VIEW O.P.H.

5.4 SECOND CASE STUDY - HILLSBOROUGH FIRST AND MIDDLE SCHOOL

Description of the Building

Hillsborough First and Middle School is one of the buildings in the 'Hillsborough Energy Action Area', Sheffield Council's pilot project, which is described earlier in this chapter.

The building was constructed in the early part of this century and is a good example of the typical construction of that era. The walls are of solid stone and the roof is steeply pitched with slate tiles. The building has tall, relatively narrow windows which occupy less than one third of the facade area, yet because of their aspect ratio there is good penetration of daylight into the building. The building is thus an interesting contrast to the overglazed, thermally lightweight structure of more modern schools such as Dobcroft (which is analysed in Section 5.2) .

Hillsborough School has a very high thermal capacity due to its solid stone construction and thus responds very slowly to its heating system. The boilers have to be set running several hours before the start of the school day to bring the building up to a comfortable temperature. The original wet radiator system is used to distribute heat through the building ; the system used to be run by oil-fired boilers but these have recently been converted to gas-firing.

The school is not extensively used outside school hours and so the occupancy patterns could be described fairly confidently. Out of hours use for night classes etc. causes problems in many other schools because it is often difficult to determine which parts of the building are heated and for how long.

Figure 5.8 shows a summary of the school produced using the

LIST command from program BUILD.

Detailed Breakdown of Monthly Consumptions

Figure 5. 9 shows the output produced from program ENMAN2 using the TABLE1 command for the period July 1981 to June 1982. The average internal air temperatures shown in the first column are predicted to be relatively high. Even though the heating is only running for ten hours per day (including pre-heat), the building has a high thermal capacity and does not cool down significantly during the 'off' period.

The degree-day base temperatures are predicted to vary between 14.4 °C and 16.8 °C indicating that traditional fixed base calculations using 15.5°C could be more applicable to this building than to others such as Green Oak View Old Peoples' Home.

Figure 5.10 shows a plot of the predictions from the final column of Figure 5.9 together with the actual metered consumptions. The correlation between the actual and calculated consumptions is very good apart from a significant discrepancy in March 1982 where the metered consumption exceeded the calculated energy requirement by some 1700 Therm . The reason for this was never discovered because the calculations were not actually made until the middle of 1983 and it was not possible to trace any fault in the heating or control system that had occured several months previously. In future such a discrepancy could be investigated much sooner.

To assess the effect of thermal capacity on the calculations of energy requirement, the building was temporarily assigned a response factor of 3 as if it were of lightweight construction. The modified output using the TABLE1 command is shown in Figure 5 . 11 and comparisons with Figure 5.9 clearly indicate the lower average internal air temperatures calculated by the mathematical model. These lower temperatures are a result of the building being expected to cool down more rapidly during the 'off' period. The calculated fuel requirements for the hypothetical lightweight building are lower as a consequence. This relates to the work of Spooner (25) which suggested that lightweight buildings are only observed to consume less energy for space heating because of their lower average internal temperatures.

Although the calculated fuel requirements for the lightweight building are lower, frost protection may be required for such a building during the winter in the form of background heating at night. In addition, solar gains could probably not be always fully utilised by the lightweight building because peaks of solar gain would not be naturally controlled. Both these factors are not yet fully accounted for by ENMAN and so the predictions of energy requirement may be optimistic for the lightweight building.

As a thermally heavyweight building with predictable patterns of occupancy, Hillsborough School was expected to fit the model closely and the results tend to bear this out. Had the School been of lightweight construction with large areas of glazing the assumptions made about the utilisation of solar gains may not have been valid and this would have an effect on the results during the Spring-Autumn period as discussed in Section 3.3 .

Regression Line Analysis

Figure 5.12 shows a plot of actual energy consumption versus calculated energy requirement for thirty-six individual months covering the period October 1980 to September 1983. This plot was produced by using the PLOT4 command from program ENMAN2.

The solid line represents the least squares best fit to the plotted points while the dotted line represents the equivalence of predicted and actual consumption and thus has a gradient of unity and passes through the origin.

Observing the scatter of points about the dotted line, there is very good agreement between actual and predicted consumption particularly when the energy consumption is below 3000 Therm. (generally February to November) . There are larger discrepancies in some of the colder months , however the least squares best fit or regression line indicates a very good overall correlation between predicted and actual consumption.

The gradient of the regression line is calculated to be 1.12 with an intercept of 9 Therm on the y-axis. In broad terms,therefore, it could be stated that during the three year period actual consumption exceeded predicted consumption by 12% on average.

The good agreement during the warmer months is substantiated by the intercept lying very near to the origin. This would tend to indicate that hot water consumption, which forms a relatively large proportion of total consumption in these months, is following the predictions closely.

Moving Yearly Totals and Cumulative Consumptions

The plot shown in Figure 5.13 gives a much better indication of the overall performance of the building than the plot of monthly consumptions shown in Figure 5.10 . The effect of moving yearly totals is to iron out the discrepancies of individual months.

The plot shows that, in the long term, the trend of actual consumption lies within very reasonable limits of the predicted consumption. Figure 5.14 lists some of the data used to produce the plot and it can be seen that the actual yearly gas consumption is approximately 30,000 Therm while predictions lie around 27,000 Therm.

During the relevant period the building thus tends to consume about 11% more fuel than it is predicted to. As such this is no cause for concern and this discrepancy lies well within the bounds of possible errors described in Section 3.7.

Figure 5.15 shows the cumulative build up of fuel consumption during 1982. It can be seen that, during this particular year, there is good agreement between predicted and actual consumption in every month except March. The discrepancy in March is discussed earlier in this section. In a cumulative graph, good agreement is indicated by the curves following parallel paths; in March they are seen to diverge.

ED 124 HILLSBOROUGH F&M

TYPE 1

FLOOR AREA	2836.0 M^2
VOLUME	8275.0 M^3
RESPONSE FACTOR	6.0
SUM OF AREAS X U-VALUES	11540.0 W/DEGC

GLAZING DETAILS

ORIENTATION	INCLINATION	AREA OF GLASS
180.0	90.0	86.0
225.0	90.0	23.0
270.0	90.0	88.0
315.0	90.0	16.5
0.0	90.0	72.0
45.0	90.0	41.0
90.0	90.0	71.0
135.0	90.0	17.0

OCCUPANCY

NO. OF OCCUPANTS	354
AV. OCCUPANCY	7.5 HRS PER DAY
	5.5 DAYS PER WEEK

FUEL DETAILS

FULE TYPE: GAS (NATURAL)
UNIT: THERM
HEAT CONTENT 29.307 KWH PER THERM
UTILISATION EFFICIENCY 60.0 %

METER READING INCLUDES SH + HW + COOKING

FIGURE 5.8

LIST OF INPUT DATA FOR HILLSBOROUGH FIRST AND MIDDLE SCHOOL

HILLSBOROUGH F&M

YEAR 1981

MONTH	AV.INT. TEMP	AV.DAILY SOLAR GAIN	TOTAL DAILY GAIN	D.DAY BASE	D.DAYS	ENERGY KWH	THERMS
JULY	18.5	677.9	1196.1	14.9	22.	9064	515
AUGUST	18.6	650.4	1168.6	15.0	0.	0	0
SEPTEMBER	18.4	586.4	1104.6	15.2	44.	14421	820
OCTOBER	17.4	379.0	897.2	15.9	186.	46736	2658
NOVEMBER	17.3	158.4	676.6	16.7	254.	62502	3555
DECEMBER	16.1	116.3	634.5	16.8	329.	78512	4465
JANUARY	16.5	154.9	673.1	16.7	353.	84782	4822
FEBRUARY	16.8	187.2	705.4	16.6	215.	52323	2976
MARCH	17.0	481.1	999.3	15.6	189.	46290	2633
APRIL	17.5	637.5	1155.7	15.0	151.	38560	2193
MAY	17.9	816.2	1334.4	14.4	101.	27455	1561
JUNE	18.4	593.3	1111.5	15.2	54.	16545	941

FIGURE 5.9 Output using the TABLE1 command

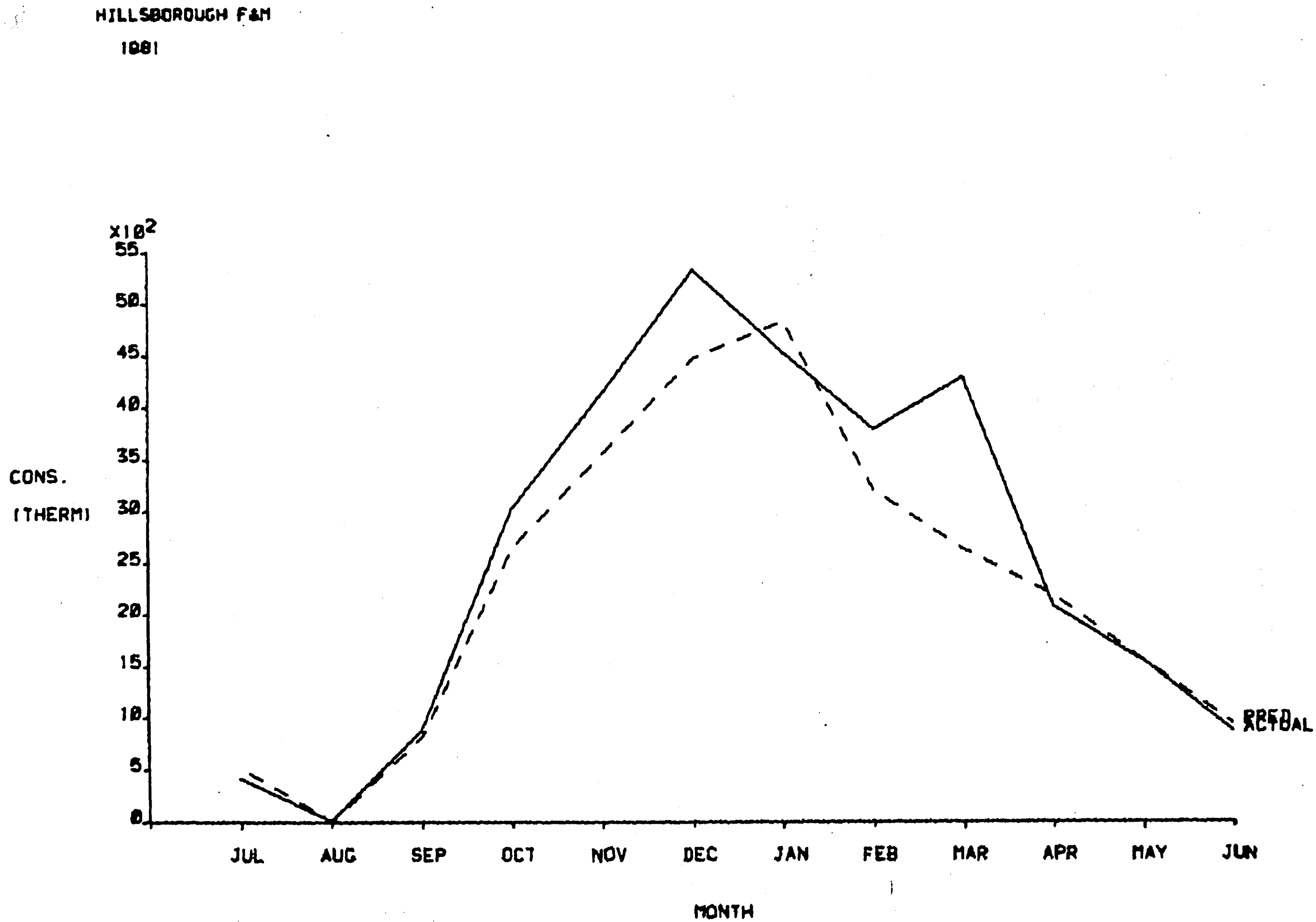


FIGURE 5.10 Output using the PLOT1 command

HILLSBOROUGH F&M

YEAR 1981

MONTH	AV.INT. TEMP	AV.DAILY SOLAR GAIN	TOTAL DAILY GAIN	D.DAY BASE	D.DAYS	ENERGY KWH	THERMS
JULY	18.2	677.9	1196.1	14.3	16.	7260	412
AUGUST	18.3	650.4	1168.6	14.4	0.	0	0
SEPTEMBER	17.9	586.4	1104.6	14.6	36.	11497	653
OCTOBER	16.2	379.0	897.2	15.4	175.	38811	2207
NOVEMBER	16.0	158.4	676.6	16.3	244.	52881	3008
DECEMBER	14.0	116.3	634.5	16.5	323.	67190	3821
JANUARY	14.7	154.9	673.1	16.3	344.	72304	4112
FEBRUARY	15.2	187.2	705.4	16.2	207.	44335	2521
MARCH	15.6	481.1	999.3	15.0	179.	38572	2194
APRIL	16.4	637.5	1155.7	14.4	137.	31346	1783
MAY	17.1	816.2	1334.4	13.7	87.	21768	1238
JUNE	17.9	593.3	1111.5	14.6	45.	13071	743

FIGURE 5.11 Output using the TABLE1 command for the hypothetical lightweight building

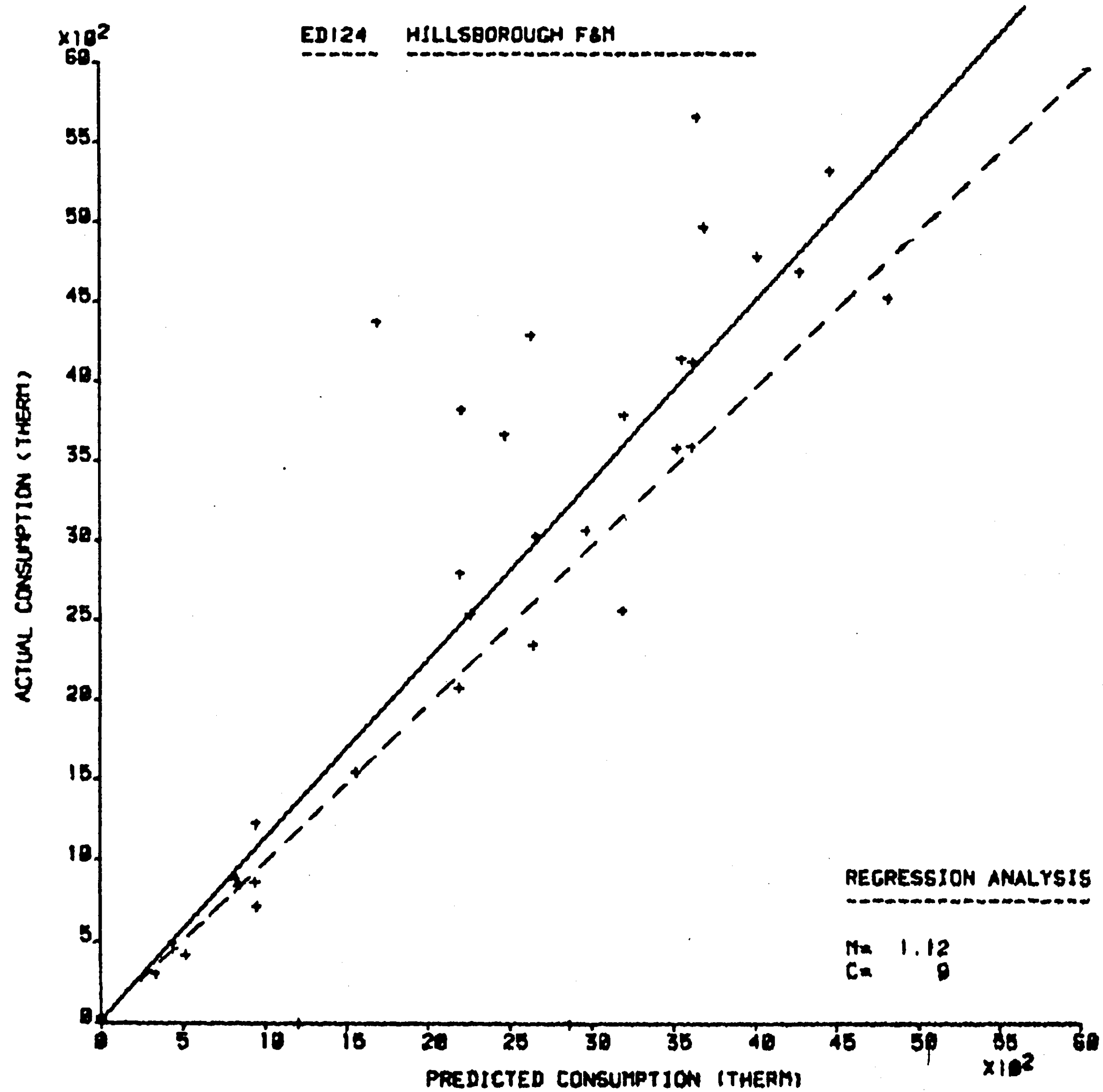


FIGURE 5.12 Output using the PLOT4 command (Oct. 1980 - Sept. 1983)

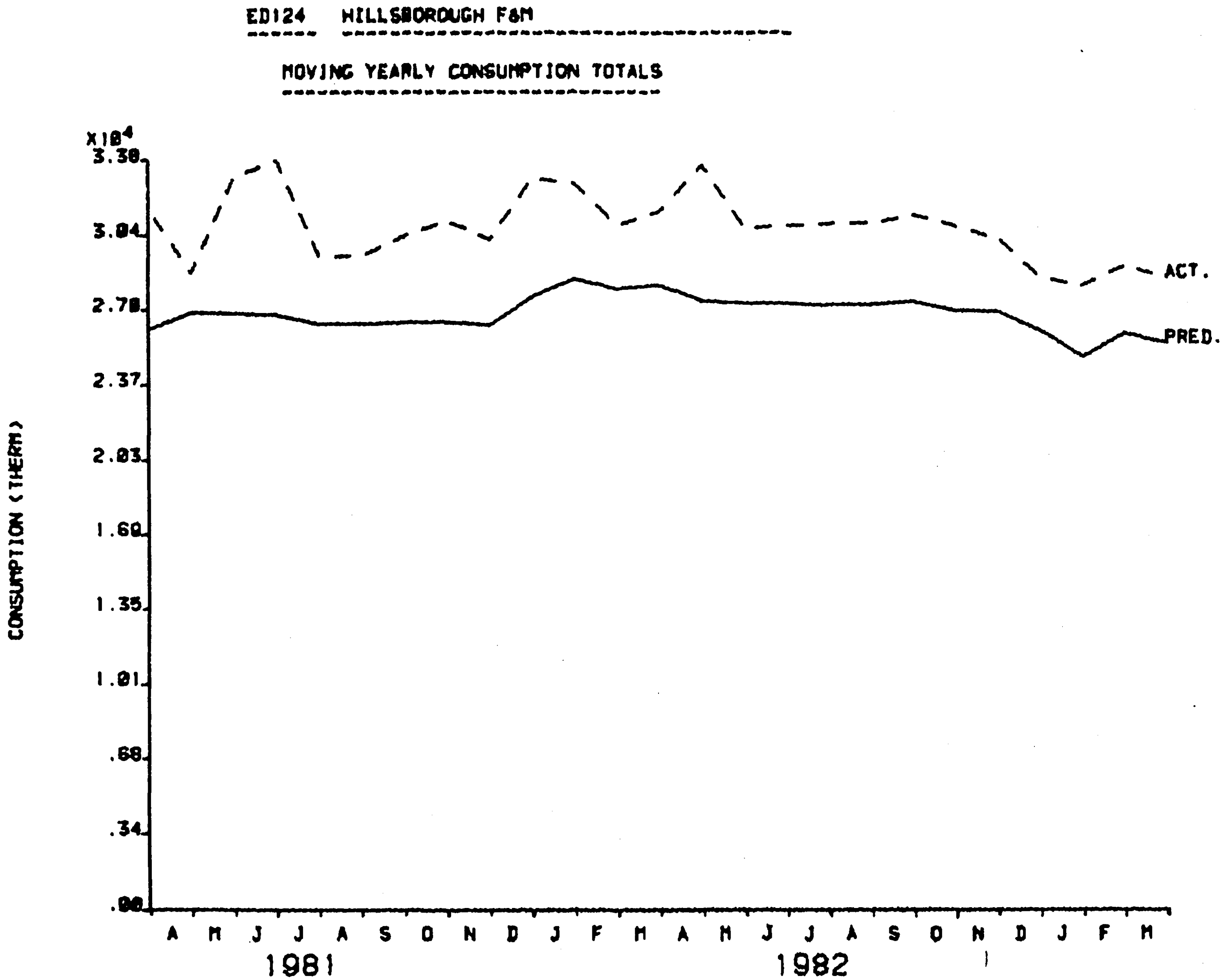


FIGURE 5.13 Output using the PLOT2 command

ED124 HILLSBOROUGH F&M

CONSUMPTIONS TO END OF MONTH (THERM)

	MONTHLY			CUMULATIVE			YEARLY TOTAL		
MONTH	PRED.	ACT.	VAR.	P	A	V	P	A	V
A 1982	2193	2080	-5%	2193	2080	-5%	27505	33571	22%
M	1561	1548	0%	3754	3628	-3%	27375	30749	12%
J	941	861	-8%	4695	4489	-4%	27366	30893	12%
J	439	486	10%	5134	4975	-3%	27290	30965	13%
A	0	33	0%	5134	5008	-2%	27290	30986	13%
S	948	1228	29%	6082	6236	2%	27418	31327	14%
O	2261	2542	12%	8343	8778	5%	27021	30836	14%
N	3527	3582	1%	11870	12360	4%	26993	30279	12%
D	3613	3592	0%	15483	15952	3%	26141	28546	9%
J 1983	3621	4120	13%	19104	20072	5%	24940	28146	12%
F	4278	4685	9%	23382	24757	5%	26015	29044	11%
M	2208	3823	73%	25590	28580	11%	25590	28580	11%

FIGURE 5.14 Output using the TABLE2 command

ED124 HILLSBOROUGH F&M

MOVING YEARLY CONSUMPTION TOTALS

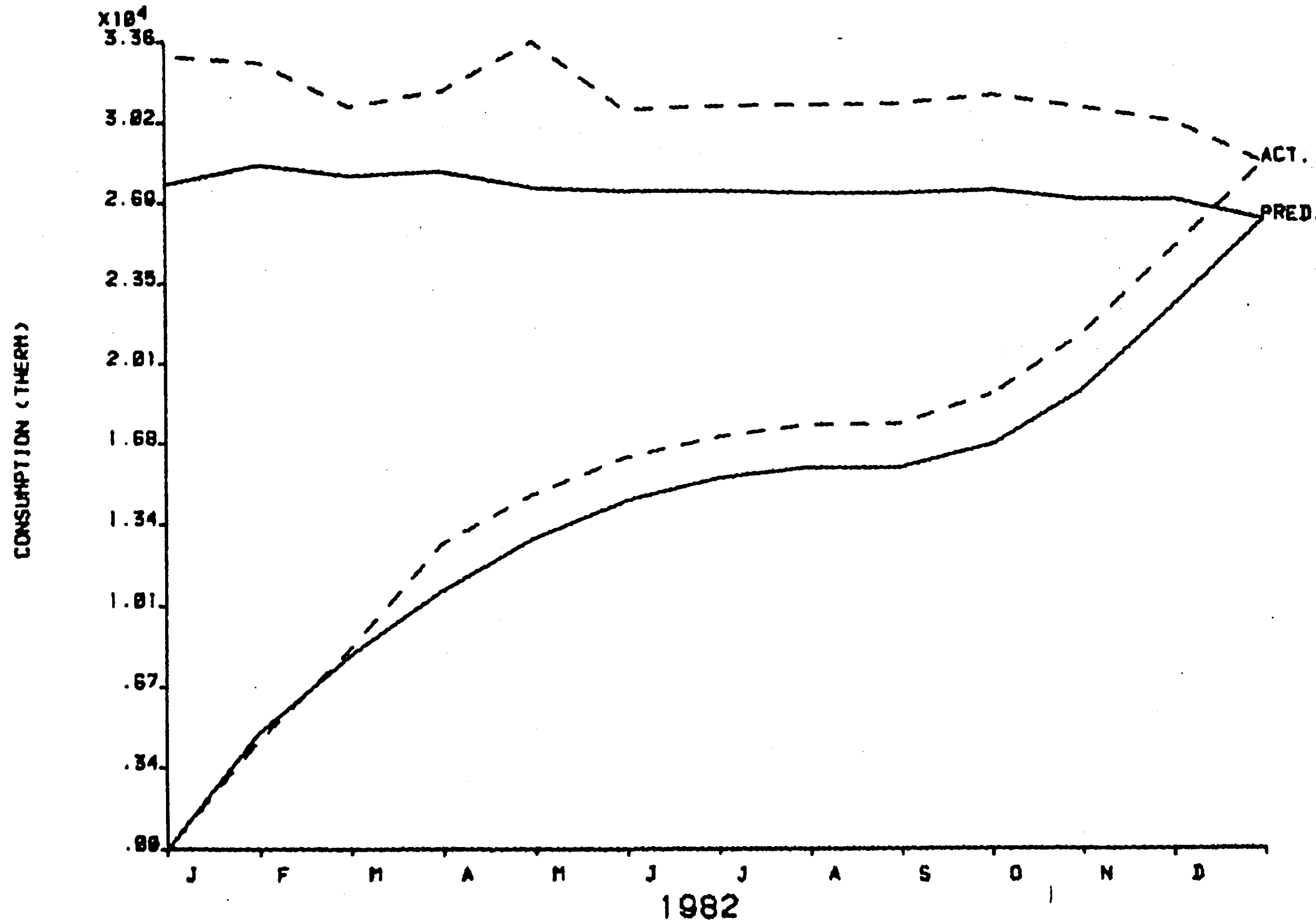


FIGURE 5.15 Output using the PLOT3 command

5.5 SUMMARY OF RESULTS FROM THE HILLSBOROUGH SURVEY

Building	Heating fuel	Units	Average annual fuel consumption 1980-1983	
			Calculated	Actual
Bowls Pavilion Hillsborough Park	Electricity	kWh	83500	21800
Branch Library	Gas	Therm	10570	5500
Dobcroft First and Middle School	Gas	Therm	15600	21800
Green Oak View O.P.H.	Gas	Therm	23200	31000
Hawkhills O.P.H.	Gas	Therm	30500	34100
Hillsborough First and Middle School	Gas	Therm	27300	30100
Holme Lane Depot	Gas	Therm	3400	2900
Malin Bridge Junior and Infant School	Gas	Therm	16700	13300
Meade House (O)	Gas	Therm	4890	5770
Mess Room Hillsborough Park	Gas	Therm	2600	600
Myer's Grove School	Oil	Litre	298200	336700
Park View Lodge (S)	Gas	Therm	31100	22600
Primrose View O.P.H.	Gas	Therm	17200	24100
Roscoe Court (S)	Gas	Therm	46200	26200
Sevenfields O.P.H.	Gas	Therm	29400	30800
Shooter's Grove Primary School	Oil	Litre	52100	40000
Sports Pavilion Hillsborough Park	Electricity	kWh	68800	36300
Stannington College	Oil	Litre	118700	280000
Stanwood Rd. Flats (S)	Gas	Therm	179700	113000

(S) Sheltered Homes (O) Office

6.1 GENERAL ASSESSMENT OF THE ENMAN SYSTEM

The ENMAN system was developed as a method of comparing the actual monthly fuel consumption of buildings with calculated requirements. The main aim of the ENMAN project has been to produce a calculation method which, in terms of complexity, falls between the simplest steady-state models and the more comprehensive dynamic thermal models. The amount of input data, required to describe each building, had to be kept to a manageable level . The computer program embodying the calculation method had to be user friendly. It is suggested that these aims have been achieved.

The ENMAN model is sensitive to important parameters such as occupancy patterns, thermal capacity and solar gain but little extra information is required from the user to describe these factors. For instance, the occupancy of a building is described by just four parameters - occupancy type, number of occupants, hours per day and days per week of occupation ; thermal capacity is described by the single parameter of response factor and this may be 'guessed' to sufficient accuracy by an experienced engineer. Many of the simpler models take no account of these important factors. The dynamic thermal models are able to take account of nearly all the parameters affecting the energy consumption of a building but great detail is usually required in the description of a building.

Other reasons for the choice of a relatively simple mathematical model have been outlined in Section 3.7. The discrepancy between the calculations of different thermal models has been shown to be less significant than the possible errors caused by the incorrect specification of input parameters such as the U-values of the building fabric. This is particularly significant for existing buildings where it is difficult to specify the thermal conductivities of different construction materials. For example, drawings rarely show the specific type of concrete blocks used in external walls but their thermal conductivity could be as little as 0.13 W/m^oC or as great as 0.8 W/m^oC. In these cases, even the most sophisticated dynamic thermal programs can give no more reliable results than much simpler calculation methods.

Because it is less sophisticated than a dynamic thermal program, another important advantage of the ENMAN computer program is that it has the potential to be mounted on relatively cheap micro-computers. At present, the cheapest machines realistically capable of running dynamic programs such as TAS^o (12) and ESP (11) cost in the region of £13,000. It would be quite feasible to mount ENMAN on microcomputer systems costing from as little as £1,000.

6.2 EXPERIENCE IN THE USE OF THE ENMAN SYSTEM

When plans of a building have been available, the gathering of the information required by ENMAN for each building has involved between one and two man-days work. The largest proportion of time is spent measuring areas and assessing the construction of each external element of the building for the purpose of calculating the fabric heat conductance ΣAU. As shown in Section 3.7, errors in the specification of ΣAU have the greatest effect on the reliability of subsequent calculations and so it has been worthwhile to concentrate effort on the determination of ΣAU. When plans have not been available, for older buildings and many of those designed by consultants outside the City Council, a physical survey has been necessary and this has been more time-consuming.

The collection of information for the buildings in the

Hillsborough Energy Action Area has involved a total of approximately twenty man-days work. It has been assessed that £ 1.25 million of capital energy-saving projects with feasible payback period have been identified during the Hillsborough survey. Although only a proportion of these projects can be attributed to the findings of ENMAN and ENGY, the time spent in the collection of information has been considered well worthwhile.

Reactions of users to the ease of operation of the ENMAN programs were initially mixed but modifications were made in the light of their criticisms. It is significant that users who had no previous experience of operating computer terminals or programs were able to use ENMAN after only a very short period of instruction. The use of menus has made the biggest contribution to the user friendliness of the programs.

It is difficult to comment about the accuracy achieved from the ENMAN energy model. One encouraging aspect has been that buildings which had previously been suspected of having efficient and well-controlled heating systems have been shown to have consumptions in good agreement with calculated requirements e.g. High Green Comprehensive School and Hillsborough First and Middle School. Stannington College had been suspected of having inadequate heating controls and excessive levels of ventilation and ENMAN showed a large discrepancy between calculated and actual fuel consumption.

There have been a small number of anomalies however. For example Shooter's Grove Primary School has consumed significantly less fuel than predicted. This trend was also exhibited in the sheltered homes (see Section 5.5) but this was not necessarily thought to be a fault of the model, rather the fact that the hours of occupancy had been entered as 24 hours per day as for old peoples' homes. It is now thought unlikely that the sheltered homes are heated continuously, but because their heating is controlled by each individual tenant it has been difficult to establish an average pattern of heating usage.

6.3 FUTURE DEVELOPMENTS

There are five areas where future modification of the ENMAN system could enhance its performance :-

(i) It is possible that the assessment of the utilisation of solar heat gains could be improved, particularly in buildings of low thermal capacity with large areas of glazing. Further developments in the research of this topic may allow the ENMAN model to be modified .

(ii) At present, recorded readings of fuel consumption have to be fed into the computer manually using the FUEL menu in program UPDATE. The Gas and Electricity Boards are currently investigating methods of direct billing where a customer is sent details of recorded fuel consumption in a digital form through a direct data link. In this way ENMAN could access this information directly withoud the need for a user to type in information from monthly fuel invoices.

(iii) Many Computer Aided Design (CAD) systems now have the potential to store data representing three-dimensional models of buildings. Instead of being stored as a set of two-dimensional drawings, buildings will eventually be described by such a model which contains all information about materials of construction, area and orientation of glazing etc. A direct link between ENMAN and such a CAD system would eliminate the time-consuming effort involved in measuring areas from plans or determining wall construction etc. For example, there are proposals within the Department of Design and Building

Services in the City Council to use the GABLE CAD system (51) to store digital models, not just of new designs but also of existing buildings. Sheffield could eventually have a database of all Local Authority owned property linked to the ENMAN system and used for other evaluative work.

(iv) There are now many systems available which allow the remote monitoring and control of heating systems and their controls. These are aimed to ensure that boilers are being operated at maximum efficiency and that temperatures are being controlled to acceptable levels. Links between such systems and ENMAN could allow the continual monitoring of fuel consumption and a deeper,day to day analysis of a building's energy performance.

(v) Computer hardware is continually developing. Because ENMAN was required to be used by different departments in the Council it was originally decided to mount the program on the mainframe computer. However this machine is fairly heavily loaded and response times are slow. The interactive performance of ENMAN could be significantly improved if the program was mounted on a dedicated desktop computer or one of the latest generation of 32-bit Virtual Memory mini-computers.

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A study of heating energy requirements and condensation and mould growth problems in the Hawley Street flats using the interactive computer program ENGY

by

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Introduction

The results reported in this paper were obtained using the interactive program ENGY, which was developed in the Department of Building Science, University of Sheffield. The program was run at the University as a Familiarisation exercise for Mr M Barnfield, the Research Assistant supported by the SMD. Mr Barnfield is currently engaged in transferring the program to the Town Hall and Polytechnic computers and all future studies will be made on these machines. The continued co-operation of the Department of Building Science is acknowledged with gratitude.

The paper deals with the problems of condensation and mould growth encountered in various sections of the Hawley Street flat buildings. Energy costs and internal temperature conditions are also investigated. All the results are for flats on the top floor as these are likely, for the following reasons, to have the greatest problems:

(i) Considerable heat losses occur through the roof area.

(ii) The external walls are thinner than on other floors.

(iii) The overall exposure of the flats is greater.

As the flats are to be converted structurally it was decided to run the program for the most likely structural proposal rather than the existing structure. Consultation with the architects revealed that proposal 'A' was most likely to be implemented. All results thus refer to structural proposal 'A' with varying levels of insulation.

Before running the program certain essential information concerning the form and nature of the construction had to be obtained. Areas of the components through which heat is lost were obtained from drawings and the corresponding U-values were determined. In addition it was necessary to make assumptions about moisture emission rates and heat inputs: these were made after visiting a number of the flats involved, the feeling being that accurate estimates of this data could only be made after actual observation of heating facilities etc. Heating by gas is assumed throughout, as this was observed to be the predominant energy source.

Once the information had been obtained it was possible to run the program and so produce predictions for various standards of insulation of the structure. The predictions show clearly the comparative merits of the various insulation schemes considered.

1 <u>Structural proposal 'A' with existing insulation standard</u>

At present there is no roof insulation and the external walls of all top floor flats have a U-value of approximately 2.4 $Wm^{-2}\,^{o}C^{-1}$. At this level of insulation the problems at Hawley Street are not unexpected.

The results of ENGY for the existing fabric are strongly substantiated by observation, with condensation predicted on all external walls and widespread mould growth at any realistic heat input. For instance, an input of 8 kW would be required, assuming ventilation of 1 air change per hour, to substantially reduce the risk of mould growth.

Energy costs are also, correspondingly, very high (see Figure 1).

2 <u>Insulation Possibilities</u>

Several possible forms of insulation have been proposed including dry lining, blockwork inner leaves and double glazing.

Consultation with the architects revealed that dry lining was the preferred option for all external walls besides, possibly, those in the kitchen where space was not at a premium (blockwork to form an outer leaf with cavity insulation was suggested here). Double glazing would be considered if energy savings rendered its installation cost-effective. Roof insulation could involve 8" fibreglass in the main roofspace and 2" styrofoam or similar for the other roof area.

Thus, the effects of dry lining with 2" or 3" of styrofoam behind foil-backed plasterboard and double glazing were investigated using ENGY. The special problems of the kitchen area were dealt with separately.

By reducing the U-value of the external walls to 0.5 $Wm^{-2}\,{}^{o}C^{-1}$ (2" styrofoam) significant improvements were predicted for all environmental conditions and substantial savings in energy are implied.

Figure 1 compares the predicted energy costs with those expected if various insulation proposals were carried out.

Table 1 summarizes the risk of condensation and/or mould growth.

Some of the output from ENGY is shown by means of the example (Figure 2). All the results are available for more detailed consultation if required.

3 Special Problems of the Kitchen/Bathroom area

It was considered to be far more representative of the real situation if the kitchen was later treated separately because:

(i) there is no direct heat input to the kitchen apart from incidental gains (from cooking, hot water, refrigerators etc) and from adjoining heated rooms namely the lounge and next door's lounge.

(ii) Most of the total moisture emitted in the flat will be produced in the kitchen/bathroom area, and to treat this area as having the same level of air moisture as the rest of the flat would be unrealistic. Figure 3 indicates extensive condensation with the current standard of insulation. Also shown is the fact that the internal temperature is predicted to be very low at 8 ^{o}C (for 1 air change per hour).

The predictions for an increased standard of insulation, to a U-value of 0.40 Wm^{-2} $^{o}C^{-1}$ (E-WALL and W-WALL) and 0.45 Wm^{-2} $^{o}C^{-1}$ (S-WALL) shows no condensation risk and, so long as a ventilation rate greater than 1 air change per hour is maintained, mould growth would also be eliminated. An extractor fan would enable the appropriate air change rates to be produced at times of high moisture emission.

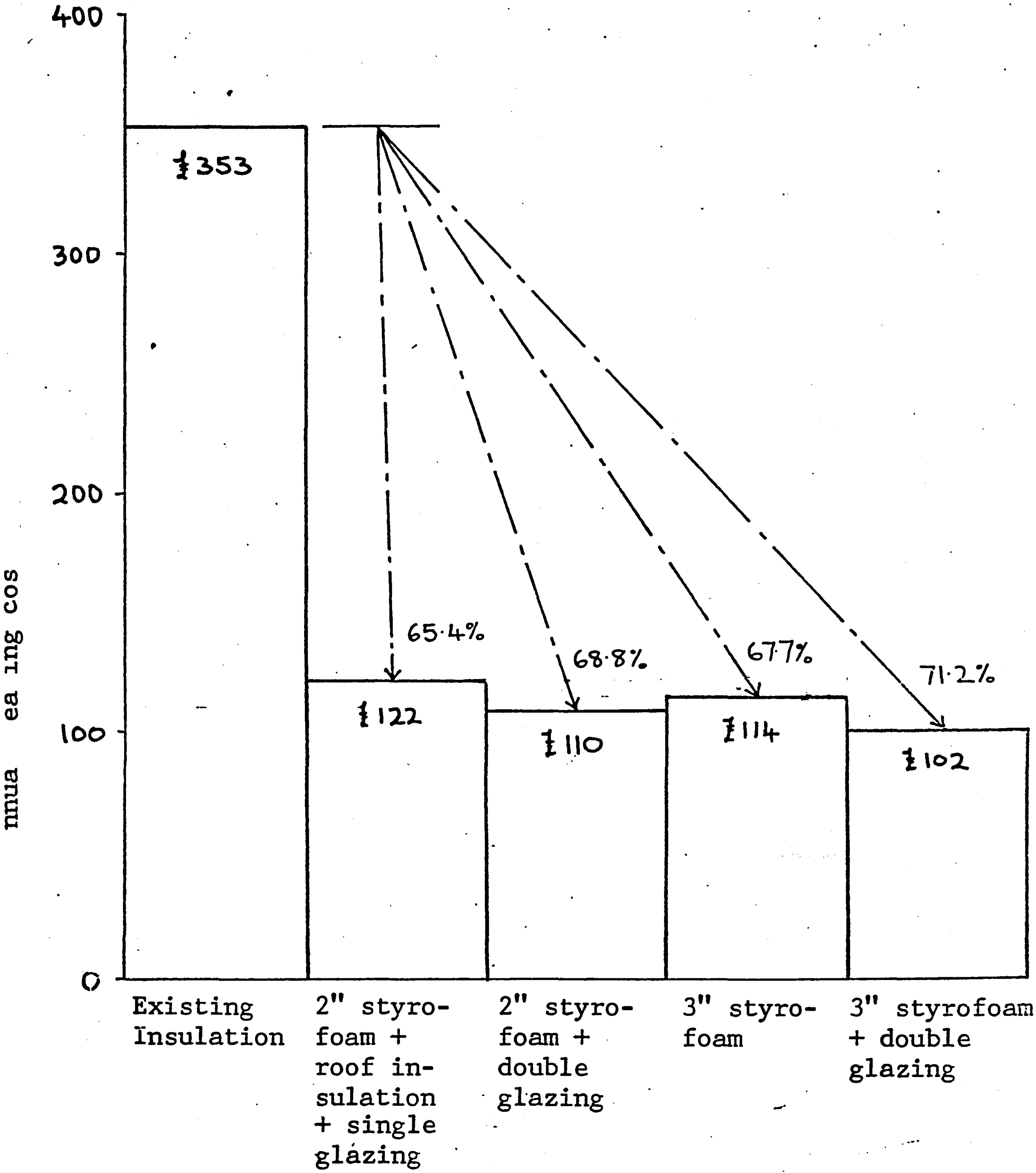
The internal temperature would also be expected to be higher at about 15 ^{o}C (see figure 4), note that this still assumes no additional heat input.

Of course the same results could be obtained for any insulating materials providing the total U-value of each wall was kept to approximately the same value of 0.40/0.45 Wm^{-2} $^{o}C^{-1}$. 3" of styrofoam behind foil-backed plasterboard would achieve a U-value of 0.37 Wm^{-2} $^{o}C^{-1}$.

It is felt that any lesser degree of insulation would result in the possibility of mould growth. In addition to an improved standard of thermal insulation, installation of a radiator or central heating boiler in this area would further reduce the risk of condensation or mould growth problems occurring.

FIGURE 1

ANNUAL HEATING COSTS FOR STRUCTURAL PROPOSAL 'A'



Note: these costs refer to the maintenance of an average internal temperature of 17 °C throughout the flat

Table 1 Mould Growth and Condensation at 1 ac/h

(a) Whole flat

Insulation	Heat input (kW)	Condensation Low †	High	Mould growth Low	High
Existing	2.0	YES	YES	YES	YES
	8.2	NO	NO	NO	NO
Dry lining	3.3	NO	NO	NO	NO
(2" styro-foam) + roof in-sulation	2.0	NO	NO	NO	YES

(b) Kitchen/Bathroom

Existing	-	YES	YES	YES	YES
Proposed blockwork + roof ins	-	NO	NO	NO	POSSIBLE*

* could be eliminated by increasing ventilation to 1½ ac/h or by providing some extra background heating eg by siting central heating boiler in kitchen

† note : low and high refer to the estimates of moisture emission rate within the dwellings

DESIGN - PROP'A' DRY LINING+DOUBLE GLAZING

ANNUAL HEATING ENERGY REQUIREMENT AND FUEL COST

BASED ON VARIABLE DEGREE DAY BASE TEMPERATURES

(N.B. FUEL COSTS EXCLUDE ANY STANDING CHARGE)

SITE IS IN REGION NO. 11 SHEFFIELD

FUEL TYPE GAS(NATURAL)
BASIC UNIT THERM   HEAT CONTENT 29.3 KWH PER THERM
UTILISATION EFFICIENCY 60.0 %   RETAIL COST 24.80 PENCE / THERM
COST PER USEFUL KWH 1.41 PENCE

AVERAGE INTERNAL TEMP. = 17.0 DEG.C

AIR CHANGE RATE = 1.0 AC PER HOUR
ORIENTATION OF REF. PLANE = 15.0 DEG. FROM N.

MONTH	DEG DAY BASE (DEG.C)	DEGREE DAYS	ENERGY (KWH)	ENERGY/ FLOOR AREA (WH/M^2)	COST (POUNDS)	COST/ FLOOR AREA (POUNDS/M^2)
JAN	13.18	237	1044	16845	14.73	0.24
FEB	13.18	218	953	15377	13.44	0.22
MAR	13.18	232	844	13517	11.99	0.19
APR	13.18	159	579	9322	8.16	0.13
MAY	13.18	90	323	5203	4.02	0.07
JUN	13.18	34	124	1963	1.74	0.03
JUL	13.18	16	59	909	0.83	0.01
AUG	13.18	18	65	1053	0.92	0.01
SEP	13.18	49	145	2348	2.65	0.03
OCT	13.18	111	404	6516	5.70	0.09
NOV	13.18	199	724	11679	10.21	0.16
DEC	13.18	226	953	15518	13.65	0.23
TOT			6237	100399	87.94	1.42

TOTAL AMOUNT OF HEATING FUEL REQUIRED   355 THERM

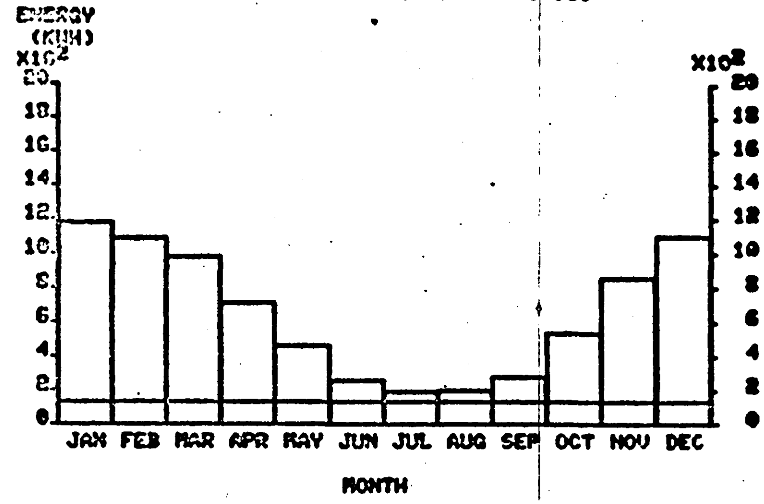
HOT WATER
MONTHLY ENERGY   133 KWH COST   1.87 POUNDS
ANNUAL ENERGY   1592 KWH COST   22.45 POUNDS
FUEL REQUIRED   91 THERM

TOTAL ENERGY   7829 KWH COST   110.39 POUNDS
TOTAL FUEL REQUIRED   446 THERM

DESIGN - PROP'A' DRY LINING+DOUBLE GLAZING

COMPT MAJOR	NO SUB	NAME	TYPE	AREA (M^2)	U-VALUE (W/M^2DEG.C)	ORIENTN (DEG.)	SLOPE (DEG.)
1		N-WALL		26.30	0.510	15.0	90.0
1	1	N-WINDWS	OPAQUE	3.60	2.500	15.0	90.0
2		BED/L		6.40	0.510	105.0	90.0
3		LIV/L		18.00	0.510	285.0	90.0
3	1	DOOR(M)	OPAQUE	1.89	3.500	285.0	90.0
4		LIV/S		8.00	0.510	195.0	90.0
4	1	S-WNDW	OPAQUE	1.30	2.500	195.0	90.0
5		W-WALL		12.30	0.510	285.0	90.0
6	1	DOOR(B)	OPAQUE	1.80	3.500	285.0	90.0
5	2	W-WINDWS	OPAQUE	1.60	2.500	285.0	90.0
6		E-WALL		12.30	0.510	105.0	90.0
6	1	E-WINDWS	OPAQUE	1.00	2.500	103.0	90.0
7		S-WALL		6.40	0.510	195.0	90.0
7	1	WC-[illegible]		[illegible]	4.500	193.0	90.0
8		ROOF(R)		[illegible]40	0.160	------	0.0
9		ROOF(K)		17.00	0.510	------	0.0

[illegible]AL ENERGY REQUIR[illegible]S AND FUEL COST F[illegible] SHEFFIELD



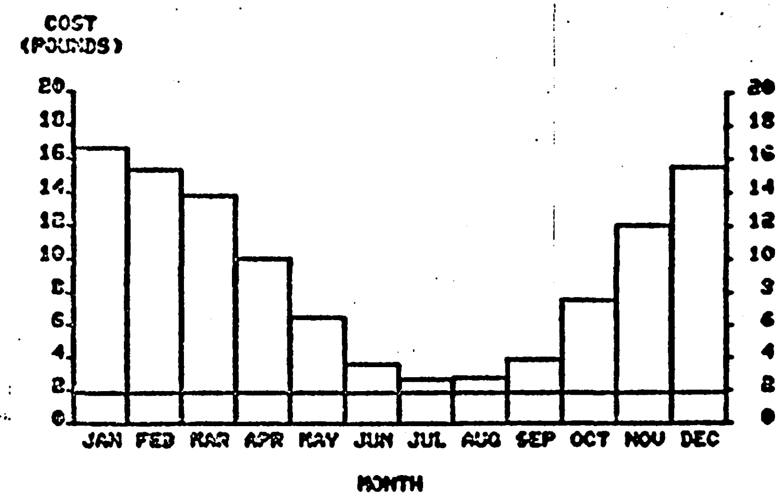


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FIGURE 2

DESIGN - KIT/BATH EXISTING INS

ACTUAL AIR TEMPERATURES AND RELATIVE HUMIDITIES

(FOR A HEAT INPUT OF 0.54 KW)

EXTERNAL AIR TEMP. = 0.0 DEG.C
EXTERNAL R.H. = 100.0% M.C. = 0.0038 KG/KG

INTERNAL RATES OF MOISTURE EMISSION
LOW RATE = 3.0 KG/DAY
HIGH RATE = 5.0 KG/DAY

COMPONENT NO. 4 S-WALL U-VALUE 2.4 W/M^2DEG.C

VENT RATE (AC/HR)	AIR TEMP (DEG.C)	RH (LOW RATE) (%)	RH (HIGH RATE) (%)	SURFACE TEMP OF COMPNT. (DEG.C)	MIN. RH (COMPT.) (%)
0.0	9.3	100	100	6.6	83
0.5	9.0	100	100	6.3	83
1.0	8.7	91	100	6.1	84
2.0	8.1	76	88	5.7	85
3.0	7.6	72	81	5.3	86
4.0	7.1	71	77	5.0	87
5.0	6.7	71	76	4.7	87
6.0	6.3	71	76	4.5	88

DESIGN - KIT/BATH EXISTING INS

COMPT. NO MAJOR	SUB	NAME	TYPE	AREA (M^2)	U-VALUE (W/M^2DEG.C)	ORIENTN (DEG.)	SLOPE (DEG.)
1		LIV/KIT		7.50	3.000	15.0	90.0
1	1	DOOR	OPAQUE	1.80	7.300	15.0	90.0
2		W-WALL		12.30	2.400	285.0	90.0
2	1	DOOR(B)	OPAQUE	1.00	3.500	285.0	90.0
2	2	W-WNDWS	OPAQUE	1.00	3.500	285.0	90.0
3		E-WALL		12.30	2.400	105.0	90.0
3	1	E-WNDWS	OPAQUE	1.00	4.300	105.0	90.0
4		S-WALL		6.43	2.400	195.0	90.0
4	1	S-WNDWS	OPAQUE	0.69	4.300	195.0	90.0
5		BATH/ND		7.50	3.000	15.0	90.0
6		ROOF		17.00	2.200	------	0.0

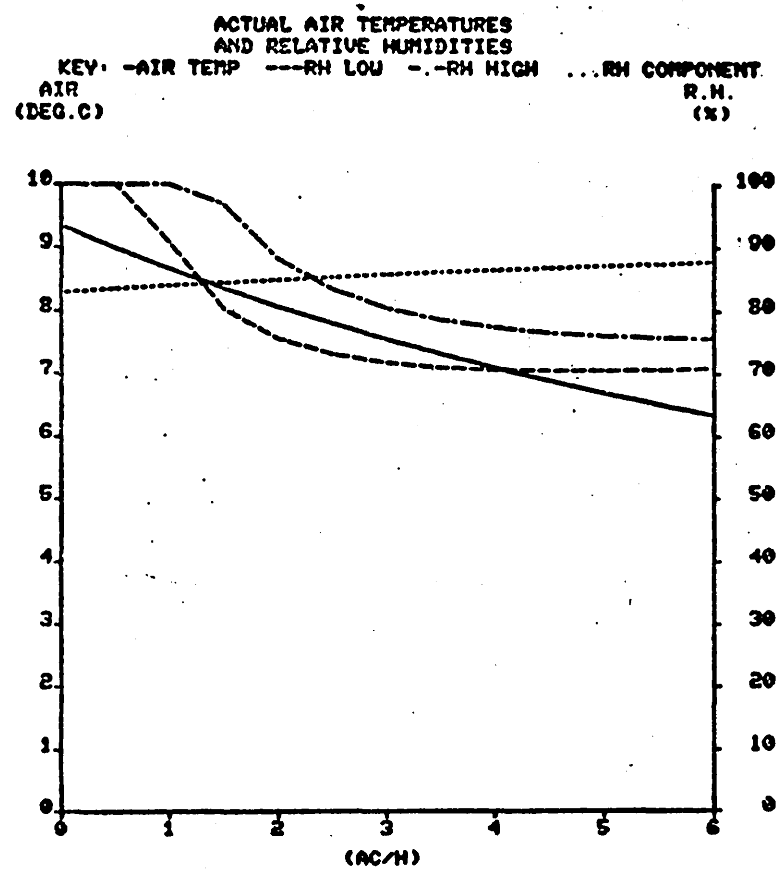

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FIGURE 3

DESIGN - KIT/BATH PROPOSED BLOCKWORK

ACTUAL AIR TEMPERATURES AND RELATIVE HUMIDITIES

(FOR A HEAT INPUT OF 0.54 KW)

EXTERNAL AIR TEMP. = 0.0 DEG.C
EXTERNAL R.H. = 100.0% M.C. = 0.0038 KG/KG

INTERNAL RATES OF MOISTURE EMISSION
LOW RATE = 3.0 KG/DAY
HIGH RATE = 5.0 KG/DAY

COMPONENT NO 4 S-WALL U-VALUE 0.4 W/M^2DEG.C

VENT RATE (AC/HR)	AIR TEMP (DEG.C)	RH (LOW RATE) (%)	RH (HIGH RATE) (%)	SURFACE TEMP OF COMPNT. (DEG.C)	MIN. RH (COMPT.) (%)
0.0	17.9	100	100	16.9	94
0.5	16.7	75	100	15.7	94
1.0	15.6	53	73	14.7	95
2.0	13.8	52	63	13.0	95
3.0	12.3	52	58	11.6	96
4.0	11.2	54	59	10.5	96
5.0	10.2	56	60	9.6	96
6.0	9.4	58	61	8.9	97

DESIGN - KIT/BATH PROPOSED BLOCKWORK

COMPT. NO MAJOR	SUB	NAME	TYPE	AREA (M^2)	U-VALUE (W/M^2DEG.C)	ORIENTN (DEG.)	SLOPE (DEG.)
1		LIV/KIT		7.50	3.000	15.0	90.0
1	1	DOOR	OPAQUE	1.80	7.300	15.0	90.0
2		W-WALL		12.30	0.400	285.0	90.0
2	1	DOOR(B)	OPAQUE	1.80	3.500	285.0	90.0
2	2	W-WNDWS	OPAQUE	1.00	3.500	285.0	90.0
3		E-WALL		12.30	0.400	105.0	90.0
3	1	E-WNDWS	OPAQUE	1.00	4.300	105.0	90.0
4		S-WALL		6.40	0.450	195.0	90.0
4	1	S-WNDWS	OPAQUE	0.60	4.300	195.0	90.0
5		BATH/ND		7.50	3.000	15.0	90.0
6		ROOF		17.00	0.510	------	0.0

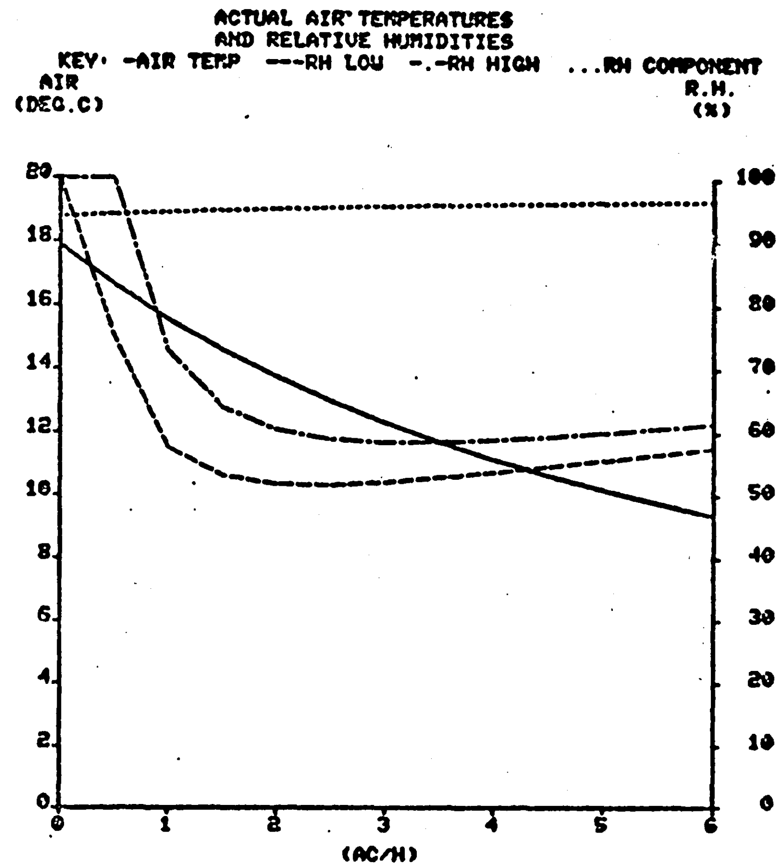

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FIGURE 4

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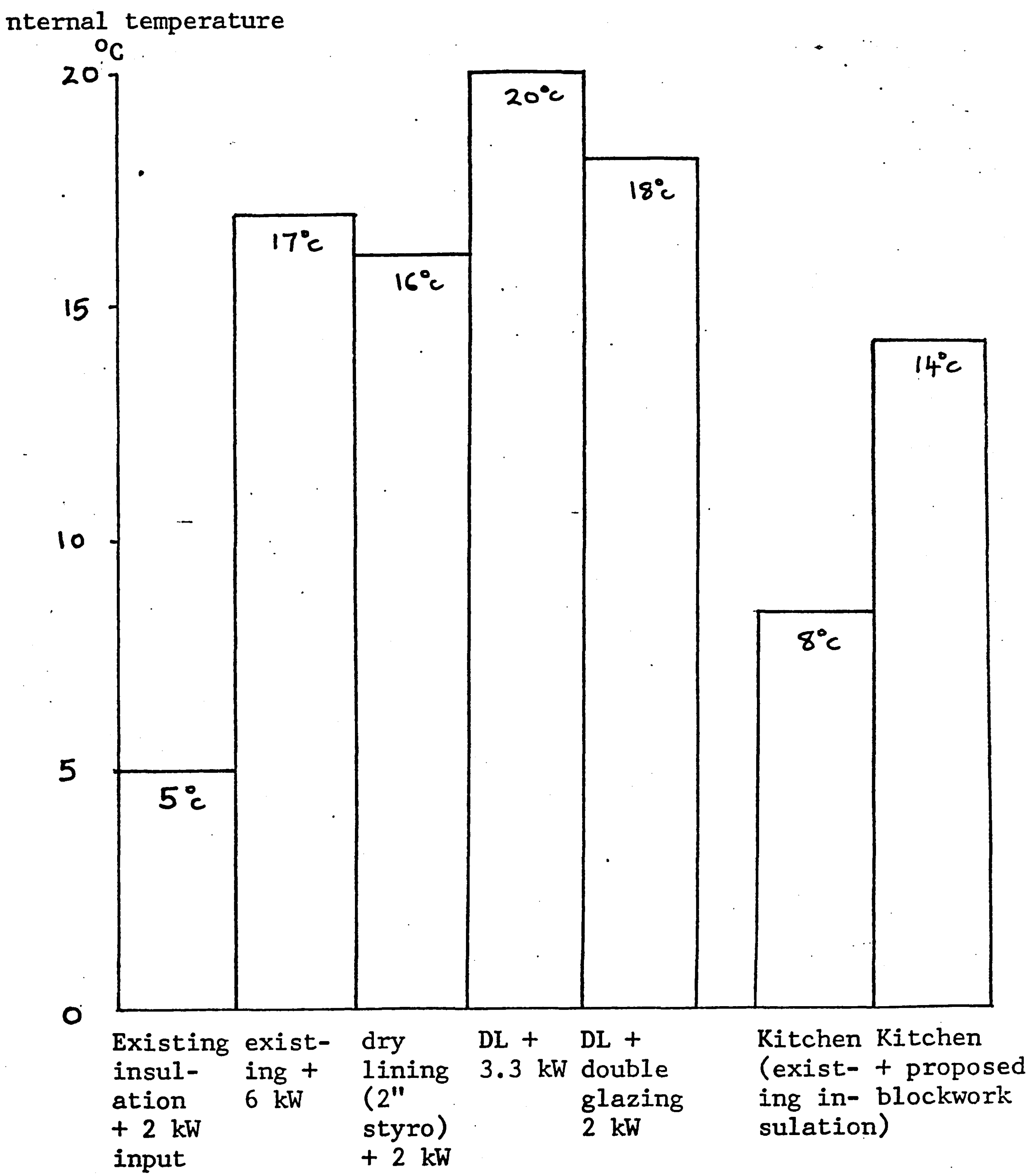
FIGURE 5

PREDICTED INTERNAL TEMPERATURES FOR DIFFERENT HEAT INPUTS



Note: all temperatures are for ventilation of 1 air change per hour

Glossary

B_m	Monthly mean direct beam irradiance	W/m^2
B_{cl}	Clear sky direct beam irradiance	W/m^2
d	Glass thickness	m
D_m	Monthly mean diffuse irradiance	W/m^2
D_{cl}	Clear sky diffuse irradiance	W/m^2
D_{oc}	Overcast sky diffuse irradiance	W/m^2
G_m	Monthly mean global irradiance	W/m^2
i	Angle of incidence	^{o}
n	Glass refractive index	-
r	Angle of refraction	^{o}
R_b	Correction function for the interpolated average direct beam irradiance	-
R_d	Correction function for the interpolated average sky diffuse irradiance	-
R_g	Ratio of ground reflected irradiance on an inclined surface to global irradiance on a horizontal surface	-
S	Monthly average daily sunshine	hrs
T	Glass transmittance	-
$\rho_{\parallel}$	Reflection coefficient for incident light travelling parallel to the glass normal	^{o}
$\rho_{\perp}$	Reflection coefficient for incident light normal to the glass normal	^{o}
σ_{rel}	Relative sunshine probability or monthly mean of hourly relative sunshine duration at a given solar altitude relative to the hourly relative sunshine duration predicted at a solar altitude of 90^o	-
σ_{drel}	Daily integral of the relative sunshine probability, σ_{rel}, for a specified month (relative sunshine weighted daylength)	hrs
μ	Glass absorption coefficient	-

APPENDIX IIA

DERIVATION OF THE MONTHLY SOLAR GAIN COEFFICIENTS

Calculation of the hourly inclined surface irradiances B_{cl}, D_{cl} and D_{oc} proceeds as described in reference 18 but includes corrections for glass transmission as shown in Appendix IIB.

Correction functions R_b and R_d are applied to take account of 'Relative Sunshine Probability'. Relative Sunshine theory takes note of the fact that the sun is more likely to be obscured by cloud at low altitude than when the solar beam is predominantly normal to the cloud plane :

$$B_m = R_b \sigma_h B_{cl} \qquad \text{IIA.1}$$

$$D_m = R_d (\sigma_h D_{cl} + (1 - \sigma_h) D_{oc}) \qquad \text{IIA.2}$$

where, $\sigma_h = (\sigma_{rel} / \sigma_{drel}) S$

$$R_b = ((-3.34 \sigma_h + 6.92)\sigma_h - 4.066)\sigma_h + 1.48$$

$$R_d = ((0.444 \sigma_h -2.98)\sigma_h + 2.54)\sigma_h + 1.0$$

now, by putting $\sigma_h = X S$, where $X = \sigma_{rel} / \sigma_{drel}$

it is possible to keep S outside all sums until the final calculation of monthly mean daily solar gain. At this stage S becomes lost in the EEC method (18).

Substitution for R_b, R_d, σ_h in equations IIA.1 and IIA.2 gives

$$B_m = B_{cl} (-3.34 X^4 S^4 +6.92 X^3 S^3 -4.066 X^2 S^2 +1.48 X S) \qquad \text{IIA.3}$$

$$D_m = (D_{cl} - D_{oc}) (0.444 X^4 S^4 -2.98 X^3 S^3 +2.54 S^2 X^2 + X S) + D_{oc} (0.444 X^3 S^3 -2.98 X^2 S^2 +2.54 X S +1.0) \qquad \text{IIA.4}$$

Performing daily sums,

$$\sum B_m = -3.34 \; (S^4) \sum B_{cl} X^4 + 6.92 \; (S^3) \sum B_{cl} X^3 - 4.066 \; (S^2) \sum B_{cl} X^2 + 1.48 \; (S) \sum B_{cl} X \qquad \text{IIA.5}$$

$$\sum D_m = (S^4) \sum (X^4 (0.444 D_{cl} - 0.444 D_{oc})) + (S^3) \sum (X^3 (3.424 D_{oc} - 2.98 D_{cl})) + (S^2) \sum (X^2 (2.54 D_{cl} - 5.52 D_{oc})) + (S) \sum (X (D_{cl} + 1.54 D_{oc})) + \sum D_{oc} \qquad \text{IIA.6}$$

note that, in the above equations, S can be taken outside the summations because it has a constant value.

Now, from the EEC method ,

$$\sum G_{ms} = (\sum B_{mh} + \sum D_{mh}) R_g + \sum D_{ms} + \sum B_{ms} \qquad \text{IIA.7}$$

and substitution from IIA.6 and IIA.7 using horizontal irradiances for $\sum B_{mh}$ and $\sum D_{mh}$ but inclined surface irradiances for $\sum B_{ms}$ and $\sum D_{ms}$ yields,

$$\sum G_{ms} = a_4 S^4 + a_3 S^3 + a_2 S^2 + a_1 S + a_0 \qquad \text{IIA.8}$$

where,

$$a_4 = R_g (-3.34 \sum B_{clh} X^4 + 0.444 \sum D_{clh} X^4 - 0.444 \sum D_{och} X^4) + 0.444 \sum D_{cls} X^4 - 0.444 \sum D_{ocs} X^4 - 3.34 \sum B_{cls} X^4$$

$$a_3 = R_g (6.92 \sum B_{clh} X^3 + 3.424 \sum D_{och} X^3 - 2.98 \sum D_{clh} X^3) + 6.92 \sum B_{cls} X^3 + 3.424 \sum D_{ocs} X^3 - 2.98 \sum D_{cls} X^3$$

$$a_2 = R_g \left(-4.066 \sum B_{clh} X^2 - 5.52 \sum D_{och} X^2 + 2.54 \sum D_{clh} X^2 \right)$$

$$-5.52 \sum D_{ocs} X^2 - 4.066 \sum B_{cls} X^2 + 2.54 \sum D_{cls} X^2$$

$$a_1 = R_g \left(1.48 \sum B_{clh} X + 1.54 \sum D_{och} X + 2.54 \sum D_{cls} X \right)$$

$$+ 1.54 \sum D_{ocs} X + \sum D_{cls} X + 1.48 \sum B_{cls} X$$

$$a_o = R_g \sum D_{och} + \sum D_{ocs}$$

The results given by these algorithms have been fully checked against results from the standard EEC method and they were found to be in full agreement (a glass transmission coefficient of unity for all angles of incidence had to be assumed to simulate the absence of glazing).

APPENDIX IIB

CORRECTIONS FOR GLASS TRANSMISSION

The reflection coefficient of a sheet of glass,for light arriving at an angle of incidence of i to the glass normal,may be calculated form Fresnel's Equations :

$$\rho_{\perp} = \frac{\sin^2 (i - r)}{\sin^2 (i + r)}$$

$$\rho_{\parallel} = \frac{\tan^2 (i - r)}{\tan^2 (i + r)}$$

where, the angle of refraction , r , may be calculated from Snell's Law :

$$\frac{\sin i}{\sin r} = n$$

or, $$r = \arcsin \left(\frac{\sin i}{n} \right)$$

Following Holmes' (46) adaptation of the procedure described in references (41) and (42), the components of incident light normal and parallel to the plane of incidence are considered separately such that,

$$T_{\perp} = \frac{T_a (1 - \rho_{\perp})^2}{1 - T_a^2 \rho_{\perp}^2}$$

and,
$$T_{\parallel} = \frac{T_a (1 - \rho_{\parallel})^2}{1 - T_a^2 \rho_{\parallel}^2}$$

T_a takes account of the absorption of light by the thickness of glass, d / cos r , through wich the refracted light has to pass :

$$T_a = e^{-(\mu d / \cos r)}$$

The transmittance, T, may now be expressed :

$$T = \tfrac{1}{2} (T_{\perp} + T_{\parallel})$$

T has a different value for each angle of incidence.

Glossary

A	Area	m^2
B	Water's method - incidental heat gains	W
	ENMAN method - intermittency factor	-
D	Degree-days	^oC day
E	Fraction of plant heat input which is realised at the environmental point	-
f	Decrement factor	-
f_r	Total building response factor	-
F	Weighting parameter	-
H	Heating plant ON time per day	hrs
H_p	Heat requirement from the heating plant	kWh
K	Fraction of plant heat input which is realised at the air point	-
n	Ventilation rate	ac/hr
N_s	Number of days in the heating season	day
Q	Heat flow or heat input	W
r	CIBS intermittency factor	-
t	Temperature	^oC
U	Thermal transmittance or U-value	$W/m^{2o}C$
Y	Admittance factor	$W/m^{2o}C$

subscripts:

a	internal air temperature point
c	internal control temperature point
d	design value
e	environmental temperature point
i	inside
o	outside
p	plant
u	with respect to steady heat flow
v	with respect to heat flow by ventilation
y	with respect to cyclic heat flow into an admittance
θ	time of day

APPENDIX III

COMPARISON OF CALCULATION METHODS AND ERROR ANALYSIS

Example Building

An imaginary two-storey classroom block is represented by the plan shown in Figure III.1 . The block is subdivided into 20 classrooms each having dimensions of 10 x 5 x 3m high. For simplicity there is assumed to be no corridor. Each classroom has 10 m^2 of glazing and external walls are of brick-cavity-block construction. Internal partitions are solid plastered blockwork and the floors and roof are solid cast concrete. The material properties of each building element are listed in Table III.1 which contains values of thermal transmittance, admittance and decrement factor taken from Section A3 of the CIBS Guide.

Incidental heat gains are assumed to be 350 kWh per day. This roughly equates with the heat production from 300 bodies, 10 W/m^2 lighting gains and representative winter solar gains. Heating plant operation is 12 hours total including 3 hours preheat per day and the building is heated 7 days per week to a design temperature of $20^{o}c$. Ventilation is assumed to be constant at 1½ air changes per hour.

Outside conditions are taken to be 30 identical days with a maximum daily air temperature of $10^{o}C$ and a minimum of $0^{o}C$.

Note

The CIBS Guide gives no guidance on the admittance factors for floors in contact with the ground. This is probably due to the complication caused by heat capacity of soil below the floor. U-values of ground floors are usually found from tables (47) and these take account of a certain depth of soil, however there is controversy over the values given (48). Thus for the sake of this example, heat exchange with the floor will be ignored at ground level.

(1) <u>CIBS Admittance Method</u>

This method is proposed in Section A5 of the CIBS Guide . It relies on the application of an intermittency factor to the steady-state heating requirements. Account is taken of convective and radiant heat transfer by the use of proportioning factors.

$$F_v = \frac{h_{ac}\Sigma A}{1/3\ nV + h_{ac}\Sigma A}$$

$$F_u = \frac{h_{ec}\Sigma A}{\Sigma AU + h_{ec}\Sigma A}$$

$$F_y = \frac{h_{ec}\Sigma A}{h_{ec}\Sigma A + \Sigma AY}$$

$\Sigma A = 120\text{x}6 + 3\text{x}50\text{x}10 + (4\text{x}10{+}50)\text{x}6\text{x}2 = 3300\ m^2$

and from the Guide $h_{ec} = 18\ W/m^2$, $h_{ac} = 6\ W/m^2$ hence,

$F_v = 0.930$, $F_u = 0.957$, $F_y = 0.811$

$$r = \frac{\dfrac{KF_v + EF_u}{1/3\ nVF_v + F_u\Sigma AU}}{\dfrac{(1/24)\ H\ (KF_v + EF_u)}{1/3\ nVF_v + F_u\Sigma AU} + \dfrac{(1-H/24)(KF_v + EF_y)}{1/3\ nVF_v + F_y\Sigma AY}}$$

now, $\Sigma AU = 520\text{x}1.3 + 200\text{x}5.6 + 500\text{x}1.8 = 2696\ W/^oC$

$\Sigma AY = 520\text{x}3.4 + 200\text{x}5.6 + 500\text{x}4.5 + 500(4.6+5.2) + 1080\text{x}3.5$

$= 13818\ W/^oC$

$1/3\ nV = 1.5\text{x}3000/3 = 1500\ W/^oC$

and, assuming 50% convective, 50% radiative heating, $K = E = \frac{1}{2}$

hence,

$r = 1.52$

The steady-state total heat input is given by,

$$\bar{Q} = \frac{(1/3\ nVF_v + F_u \sum AU)(t_d - \bar{t}_{ao})}{KF_v + EF_u}$$

noting that $\bar{t}_{ao} = 5^{o}C$,

$$\bar{Q} = 63197\ W$$

during the preheat period a correction factor of 1.1 is used for boost input.

Thus , for 12 hours heating including 3 hours preheat the daily heat requirement is

$$(\underbrace{1.52 \times 63197 \times 9}_{\text{normal}} + \underbrace{1.52 \times 1.1 \times 63197 \times 3}_{\text{boost}})\ Wh$$

$$= 1182\ kWh$$

Assuming that all incidental heat gains are useful and have an equal radiative and convective content, then over 30 days the heat input required from the heating plant is given by,

$$H_p = (1182 - 350) \times 30$$

$$\underline{H_p = 24900\ kWh}$$

(2) Billington's Adaptation of the Admittance Procedure

Billington (49) has adapted the admittance procedure to allow the calculation of seasonal heating requirements. His two major assumptions are that plant heat inputs follow a stepped profile and internal temperatures vary sinusoidally with time such that

$$t_d = \frac{24}{\pi H} \tilde{t}_{ei} \sin \frac{\pi H}{24} + \bar{t}_{ei} \qquad (1)$$

and, $\bar{Q} = \frac{12\,Q}{24} = \frac{1}{2} Q$ (12 hour heating)

$$\tilde{Q} = Q - \tfrac{1}{2} Q = \tfrac{1}{2} Q$$

The fundamental equations of the admittance procedure are,

$$\bar{Q} = (\Sigma AU + 1/3\ nV) (\bar{t}_{ei} - \bar{t}_{eo}) \qquad (2)$$

$$\tilde{Q} = (\Sigma AY + 1/3\ nV) \tilde{t}_{ei} \qquad (3)$$

From equation (2) ,

$$\bar{t}_{ei} - \bar{t}_{eo} = \frac{\bar{Q}}{(\Sigma AU + 1/3\ nV)}$$

$$= \frac{\frac{1}{2}Q}{1500+2696}$$

$$\bar{t}_{ei} = Q / 8392 + \bar{t}_{eo}$$

From equation (3) ,

$$\tilde{t}_{ei} = \frac{\tilde{Q}}{(\quad AY + 1/3\ nV)}$$

$$= \frac{\frac{1}{2}\ Q}{13818+1500}$$

$$\tilde{t}_{ei} = Q / 30636$$

Substitution for $\bar{t}_{ei}$ and $\tilde{t}_{ei}$ in equation (1) yields,

$$t_d = \frac{24}{12\pi} (Q / 30636) \sin \frac{12\pi}{24} + (Q / 8392) + \bar{t}_{eo}$$

because solar gains are included in the 350 kWh incidental gains, we can take $\bar{t}_{eo} = \bar{t}_{ao} = 5^{o}C$ thus,

$$20 = (2 /\pi) (Q / 30636) + (Q / 8392) + 5$$

$$Q = 107.2 \text{ kW}$$

and H_p is given by,

$$H_p = (12 \times 107.2 - 350) \times 30$$

$$\underline{H_p = 28092 \text{ kWh}}$$

(3) Waters' Adaptation of the Admittance Procedure

Waters (50) developed an equation from the work of Harrington-Lynn (31) which enables the calculation of daily energy requirements. Waters' method allows the consideration of separate, low and high, rates of ventilation and incidental heat gain. In this way some account may be taken of the variation of these two parameters between the 'ON' and 'OFF' heating periods. For this example however, the ventilation rate will be assumed constant such that the following equation applies:

$$G \sum_{ON} Q_{p\theta} = C_1 (t_d - \bar{t}_o) + C_2 \sum_{ON} \tilde{t}_{o\theta} + C_3 \sum_{OFF} B_\theta - \sum_{ON} B_\theta$$

where,

$$C_1 = (Z + 1) H (1/3 \, nVF_v + F_y \sum AY)$$

$$C_2 = -(Z + 1) (1/3 \, nVF_v + F_y \sum fAU)$$

$$C_3 = Z = \frac{H (F_u \sum AU - F_y \sum AY)}{H(1/3 \, nVF_v + F_y \sum AY) + (24-H)(1/3 \, nVF_v + F_u \sum AU)}$$

$$G = KF_v + EF_y - \frac{ZE (F_y - F_u)(1/3 \, nVF_v + F_y \sum AY)}{(F_u \sum AU - F_y \sum AY)}$$

now,

$$\sum fAU = \underset{\text{walls}}{520x1.3x0.40} + \underset{\text{roof}}{500x1.8x0.33} = 567.4 \text{ W/}^\circ\text{C}$$

and, as before, taking $K = E = \frac{1}{2}$:

$$Z = -0.52 \;,\; C_1 = 72582 \text{ Wh/}^\circ\text{C} \;,\; C_2 = -890.5 \text{ W/}^\circ\text{C} \;,\; G = 0.926$$

by assuming a sinusoidal variation of outside temperature such that

$t_{o\theta} = t_o = 10^\circ C$ when $\theta = 6$ hrs and,

$t_{o\theta} = \bar{t}_o = 5^\circ C$ when $\theta = 0$

the variation of t_o may be expressed:

$$t_{o\theta} = 5 + 5 \sin \frac{\pi\theta}{12} \qquad \text{(for this chosen time scale)}$$

The value of $\sum_{ON} \tilde{t}_{o\theta}$ depends on how the heating period spans across the external temperature profile. If the 12 hour heating period is assumed to coincide exactly with $(t_{o\theta} - \bar{t}_o) = 0$ i.e. the situation of Figure III.2 then,

$$\sum_{ON} \tilde{t}_{o\theta} = \int_0^{12} \left(5 \sin \frac{\pi\theta}{12} \right) d\theta$$

$$= \left[- \frac{12x5}{\pi} \cos \frac{\pi\theta}{12} \right]_0^{12}$$

$$= 38.2 \ {}^oC \text{ hrs}$$

evaluating equation (1) and assuming that $\sum_{ON} B_\theta = 350$ KWH and $\sum_{OFF} B_\theta = 0$ (all incidental gains assumed to occur during the heating period)

$$0.926 \sum_{ON} Q_{p\theta} = 72582 \ (20 - 5) - 890.5 \ (38.2) - 350x10^3$$

$$\sum_{ON} Q_{p\theta} = 761.0 \text{ kWh} \quad \text{(for one day)}$$

For 30 identical days the plant requirement is given by,

$$H_p = 30x761.0$$

$$\underline{H_p = 22830 \text{ kWh}}$$

(4) The ENMAN Method

The building response factor would normally be estimated from a knowledge of the buildings construction or the observed response to its heating system. However for this example it can be calculated explicitly :

$$f_r = \frac{\Sigma AY + 1/3\ nV}{\Sigma AU + 1/3\ nV}$$

$$= \frac{13818 + 1500}{2696 + 1500}$$

$$= 3.65$$

the intermittency factor, B, is given by

$$B = \frac{Hf_r}{24 + H(f_r - 1)} = 0.785$$

$$H_p = \frac{24}{1000}\ B\ (\ \Sigma AU + 1/3\ nV\ )\ D(t_b)$$

where, t_b is the modified base temperature

$$t_b = t_d - t/B$$

$$t = \frac{350x1000}{(2696+1500)x24} = 3.475\ ^oC$$

thus,

$$t_b = 20 - \frac{3.475}{0.785} = 15.57\ ^oC$$

and,

$$D(t_b) = 30\ (\ 15.57 - 5\ ) = 317.1\ ^oC\ day$$

hence,

$$H_p = \frac{24}{1000} \times 0.785(\ 2696+1500\ ) \times 317.1$$

$$\underline{H_p = 25100\ \ kWh}$$

Error Analysis of the ENMAN Method

In the example the outside temperature is always less than the degree-day base temperature and so the degree-day total may be expressed :

$$D(t_b) = N_s\ (\ t_b - \bar{t}_o\ )$$

The monthly space heating energy requirement is now given by,

$$H_p = \frac{24}{1000} B U' N_s (t_d - \bar{t}_o) - H_w \quad (1)$$

where, $U' = (\Sigma AU + 1/3\ nV)$ and H_w are the incidental heat gains.

Because the internal temperature and ventilation rate are set to design values, the only independent variables which shall be considered are U' , Y' , H and H_w ($Y' = \Sigma AY + 1/3\ nV$)

An error equation may be formed thus,

$$\delta H_p \doteq \frac{\partial H_p}{\partial U'} \delta U' + \frac{\partial H_p}{\partial Y'} \delta Y' + \frac{\partial H_p}{\partial H} \delta H + \frac{\partial H_p}{\partial H_w} \delta H_w \quad (2)$$

now,

$$\frac{\partial H_p}{\partial U'} = \frac{24}{1000} N_s (t_d - \bar{t}_o) (B + U' \frac{\partial B}{\partial U'})$$

$$\frac{\partial H_p}{\partial Y'} = \frac{24}{1000} N_s (t_d - \bar{t}_o) U' \frac{\partial B}{\partial Y'}$$

$$\frac{\partial H_p}{\partial H} = \frac{24}{1000} N_s (t_d - \bar{t}_o) U' \frac{\partial B}{\partial H}$$

$$\frac{\partial H_p}{\partial H_w} = 1$$

and, since $B = \dfrac{H (Y'/U')}{H (Y'/U')+(24-H)}$,

$$\frac{\partial B}{\partial U'} \doteq \frac{(B - 1) B}{U'}$$

$$\frac{\partial B}{\partial Y'} = \frac{(1 - B) B}{Y'}$$

$$\frac{\partial B}{\partial H} = \frac{(1 - B) B}{H}$$

Substitution into equation (2) now yields,

$$\delta H_p = \frac{24}{1000} N_s (t_d - \bar{t}_o)\left(B^2 \delta U' + \frac{U'(1-B)B}{Y'} \delta Y' + \frac{U'(1-B)B}{H} \delta H \right) + \delta H_w \quad \text{.... (4)}$$

Substituting values from the example building,

$$\delta H_p = \frac{24}{1000} \text{x}30\text{x}(20-5)(\ 0.785^2 \delta U' + (4196/15318)(1-0.785)\text{x}0.785 \delta Y'$$

$$+ (4196/12)(1-0.785)\text{x}0.785 \delta H\ ) + \delta H_w$$

$$\delta H_p = 6.65 \delta U' + 0.50 \delta Y' + 637 \delta H + \delta H_w$$

Possible levels of error in the specification of building parameters are as follows :

U' : 20% of AU or 540 $W/^oC$

Y' : 20% of AY or 2760 $W/^oC$

H_w : 20% or 2100 kWh (per month)

H : 1 hour

thus,

$$\delta H_p = 6.65\text{x}540 + 0.50\text{x}2760 + 637\text{x}1 + 2100$$

$$\delta H_p = 3591 + 1380 + 637 + 2100$$

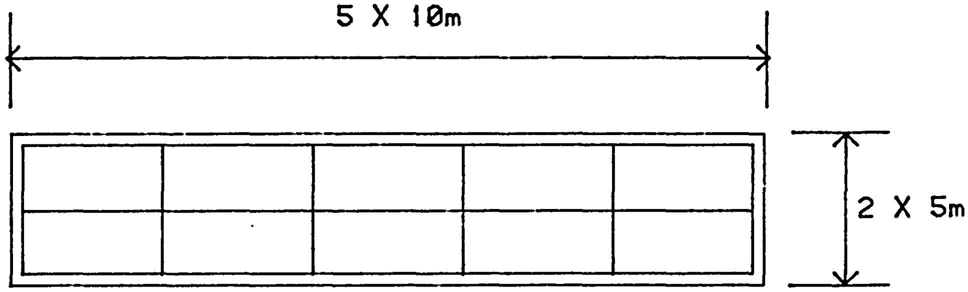
$$\delta H_p = 7708 \text{ kWh}$$

$$\underline{H_p = 25100 \pm 7708 \text{ kWh} \quad \text{OR} \pm 31\%}$$

	U-value W/m^2 °C	Admittance (Y-value) W/m^2 °C	Decrement factor, f
External walls	1.3	3.4	0.40
Internal partitions	-	3.5	-
Roof slab	1.8	4.5	0.33
First floor slab	-	4.6 (upward heat flow) 5.2 (down)	-
Glazing	5.6	5.6	-

TABLE III.1

Values of Thermal Transmittance, Admittance and Decrement Factor Used for the Example Building



2 X 3m High

FIG III.1

Plan of the Two Storey Classroom Block used for the Example

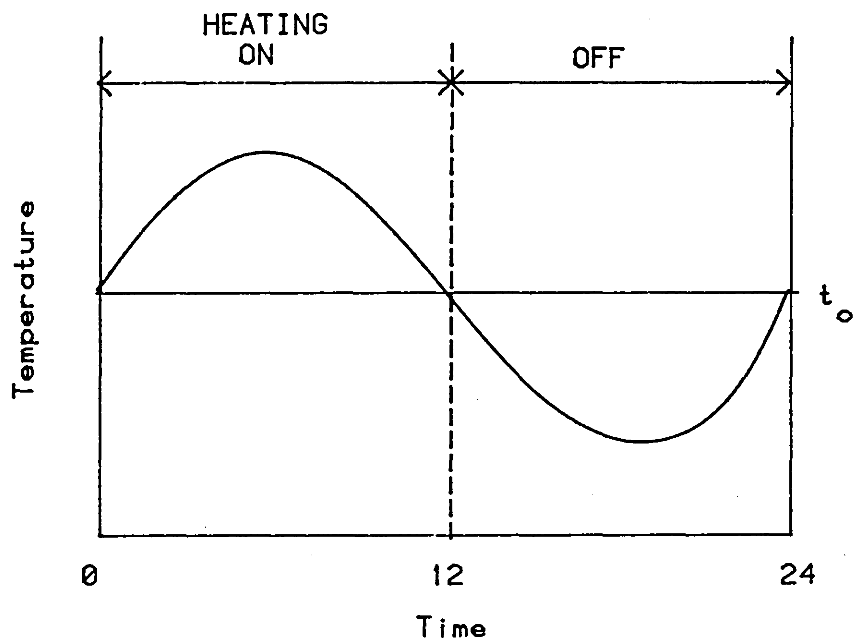


FIGURE III.2

Outside Temperature Profile Assumed for Water's Method