Models for estimating the cost of piped heating systems in buildings

PUBLISHER

Loughborough University of Technology

2

MODELS FOR ESTIMATING THE COST OF PIPED HEATING SYSTEMS IN BUILDINGS

by

ALAN STEPHEN WOOD, M.I. Mech.E.

A Master's Thesis.

Submitted in partial fulfilment of the requirements for the award of

Master of the Loughborough University of Technology

December, 1975.

Supervisor : Professor E.G. Trimble.
Department of Civil Engineering.

I declare that the extent of my contribution to this thesis is as follows :-

1. The theoretical approach to the analysis.
2. Arranging computer trials, and assessing the results.
3. Directing the collection of data, and training staff in data extraction and recording.
4. Directing the production of punch cards for input to the computer.
5. Developing and testing the PRE-NIMBUS program written by Mr. R.C. McCaffer of Loughborough University.
6. Writing the CHANGE program for transfer of data between magnetic tapes.
7. Writing the program to operate the E02ABF statistical program.

I am fully responsible for the results obtained, and for the conclusions drawn from those results. Part of the data collection, extraction and recording function was carried out by full-time and part-time staff specially employed for the purposes, whilst advice and assistance was given on statistical and computer work by the full-time staff of Loughborough University of Technology. An acknowledgment of those contributions is given later.

I N D E X

ACKNOWLEDGEMENTS

This study began with a target of 200 contracts from each of which 50 variables were to be obtained and used for cost analysis. Eventually data for 111 variables were gleaned from 200 contracts. Many people were contributors to that effort and to the statistical and computer work which enabled the data to be used for Regression Analysis.

The Property Services Agency of the Department of the Environment allowed me the privilege of undertaking this work and made available the contract data upon which it depended. In particular I extend my warmest thanks to the many P.S.A. engineers who provided contract drawings, documents and design information for over 250 heating contracts, and to Mrs. Margaret Brooks and George Humphreys who progressed the collection of contract documents in Croydon.

The extraction of contract data from the documents was undertaken at Loughborough. This painstaking task took many months to carry out and was completed through the conscientious efforts of Miss. Kate Marshall, Mrs. Denise Tarry, Nick Land and Nick Snowdon.

The Loughborough University computer was extensively used for data analysis and more than 600 separate computer runs carried out with the co-operation of the Computer Centre.

I would like to recognise the skill of Brian Negus which was invaluable on problems requiring specialist knowledge of the computer's programming facilities.

Professor G. Gregory and Mr. D.G. Johnson of the Department of Management Studies at Loughborough University were advisers on Multiple Linear Regression Analysis and statistical matters arising from the analysis.

Mr. P. Gould of John Laing Construction Ltd., kindly contributed his experiences in connection with data handling and highlighted the need for a computerised data handling facility.

I am very much indebted to Mr. R. McCaffer of the Department of Civil Engineering, Loughborough University for allowing me to use his data handling program.

The use of regression analysis to formulate cost models has been actively pursued in the field of Building Construction by Professor E.G. Trimble who has been my supervisor for this research. I am extremely grateful for his guidance and encouragement and the opportunity to benefit from his knowledge and experience of the subject.

The Building Research Establishment has kindly consented to formulae 7.1 and 7.2 being quoted from the following document - 'Treasury Research Relating to a Tender Price Index for Mechanical and Electrical Services in Buildings - Stage 1 Report'

My final thanks are reserved for my wife, Jane, for her active support, particularly in typing this thesis.

1. INTRODUCTION

The subject of this study is the establishment of models for estimating the cost of piped heating systems in buildings. The cost being considered is the price charged to the Property Services Agency of the Department of the Environment for the supply and installation of a piped heating system by a heating contractor.

The accuracy of the results obtained will be compared with the accuracy of estimating by traditional methods.

To obtain the cost models, data concerning heating contracts for the period October 1971 to March 1973 has been obtained and subjected to Multiple Linear Regression Analysis using a modified standard statistical computer program.

Access to data was made available by the Property Services Agency of the Department of the Environment, who are responsible for the design of many heating installations in Government buildings annually, and who supervise the site installation work carried out by heating contractors securing the contracts for the work.

Multiple Linear Regression Analysis (M.L.R.A.) can be performed by longhand arithmetic using slide rules, tables of logarithms and simple calculators but the vast number of calculations required by this study would have rendered it impossible to progress to any depth.

Computer programs capable of dealing with large quantities of data needing analysis by M.L.R.A. have been developed for commercial use and Loughborough University computer centre have arranged for such a program to operate on their computer.

There are various stages during the design of a piped heating system when it is necessary to estimate its installation cost so that the prospective owner of the building can be made aware of his potential liabilities.

The two vital stages are the 'preliminary sketch plan stage' of design, which is prior to commencement of detailed design work, and the 'pre-tender' stage of design when design drawings are completed and negotiations with a heating contractor are about to commence.

Before embarking on detailed design drawings the heating engineer formulates his initial ideas of the heating system required, in conjunction with the Architect's preliminary sketch plans of the building.

At that time he will be in possession of rudimentary information such as the type of building construction, the room layout, the location of the site and the function of the building. From this information he can make a calculated assessment of the winter heat losses for the building and the requirement for domestic hot water, assess the type of installation needed to meet the duty and size the boilers.

Having made these initial decisions an estimate of cost is needed for budget purposes. Establishing a cost model based on the information available at this preliminary stage of design constitutes one aim of this study.

As the detailed design progresses decisions are made which affect the layout of the plant and amend the original calculations to the extent that changes occur in the estimate of cost.

When design drawings are complete, prior to tender, the duties of all the component parts are known, giving more reliable information on which to estimate the cost of the installation. Establishing a cost model for the pre-tender stage of design is the second principal objective.

2. PRESENT METHODS OF ESTIMATING AND POSSIBLE METHODS USING REGRESSION ANALYSIS

(In the earliest stages of design the cost of the heating service within a building is often based on a unit cost such as £/m^2 of floor area, £/m^3 of building volume or £/kW of heat required to maintain the design temperature.) The Association of Consulting Engineers' scale of fees states that an estimate calculated in this fashion is to be provided by the Engineer at the preliminary stage of design.

(The estimate based on unit costs is usually adjusted for such factors as the proposed type of heating system, whether the work is in a new or existing building, remoteness of the site, the current climate of tendering and the problems associated with the installation, although this is not a complete list by any means. For any individual building there are always a multitude of reasons why cost can be expected to vary from the mean unit cost figure.)

(Because unit costs are associated with a base year an inflation factor is ususally adopted to take account of the time which elapses between the base year and the year of installation.)

THus the design Engineer's preliminary estimate is based on historical costs gleaned from jobs of a similar nature and adjusted for the current contracting situation as he sees it. His task is not easy when the details of a project which are available in the early stages may solely be the Architect's preliminary sketch plans and his own first thoughts on the type of system to employ, together with his preliminary plant layout.)

In the later stages of design he is able to seek quotations from manufacturers for the plant and equipment that he is considering for a scheme. Allied to this information he can use price lists and catalogues for standard items such as pipework in order to build up a total estimate, making due allowance for the installation labour costs, overheads and profit that a contactor will apply to the basic prices in forming his tender. As before, he must assess the value of factors such as location of the site, type of contract, the current climate of tendering and the rate of inflation to arrive at his best estimate of the likely tender price.

It is very difficult to determine the accuracy of present estimating methods in a fair manner. Without divulging their figures many estimators claim to be within 10% of the tender figure, but so many estimates are based on foreknowledge of the cost of plant to be supplied under the contract that it is not unexpected to find such a high standard of estimating. This merely proves the care with which the successful estimators investigate the best buys in order to ascertain the probable installation cost. This is to be commended and is a method of checking that the installation contractor is charging a fair price for installing the plant.

A measure of the standard of estimating at which to aim would be the ex-Ministry of Public Building & Works (now DOE/PSA) standards, where at Preliminary Sketch Plan stage the accuracy expected of the Engineer was 30%, at Final Sketch Plan stage 15% and at Pre-Tender stage 10%.

Mathematical modelling offers a means whereby the effect on cost of the many features of a heating system can be measured. Factors can be introduced into the model to show the way in which they individually influence the cost, which also allows cost comparisons between differing types of design during the initial stages of planning. This method of estimating may be a more accurate method than those in current use, and even if less accurate, may be quicker with a resultant saving in Engineer's time.

One method of constructing a model forpiped heating systems in buildings is to obtain a set of data on piped heating installations and to analyse it using a standard statistical computer program suitable for Multiple Linear Regression Analysis.

Where large numbers of variables are involved the aid of a computer in carrying out M.L.R.A. is essential because of the prohibitive number of arithmetical calculations needed.

Computer programs have been developed which allow a computer to carry out the M.L.R.A. quickly and cheaply, also providing a record of the model coefficients together with statistical information on the data used to construct the model and of the model itself. It requires that data be fed into the computer according to the program running instructions in order that the printout contains the correct data on the model. Whilst this is a straightforward operation the skill in this work lies in obtaining data, verifying it and presenting it to the computer in a manner which will give results capable of mathematical interpretation as to their relevance and significance. (Details of computer work is given in Appendix 3).

Using M.L.R.A. it might be possible to obtain a model for the preliminary stages of design which had an accuracy better than 30%, and a model for pre-tender stage of design with an accuracy better than 10%.

A preliminary stage model whose accuracy was better than 30% would be a useful estimating tool in the initial stages of design, particularly if it allowed cost comparison between differing systems of heating. The order of accuracy would be less than that of the pre-tender stage model because the variables used in the latter will not, in all cases, be available for use in the preliminary stage model.

This is because the brevity of design at preliminary stage precludes the use of full technical details upon which to base cost information. In the past Engineers have used area and volume as their basic units for estimating cost, being two factors which are determinable at that early stage. In the Author's opinion this leads to significant errors because cost is very much dependent upon the quantity of heating equipment needed in a building which in turn depends to a great extent on the amount of heat required to maintain the design environmental conditions i.e. the kW heat loss.

The losses are influenced by the structure and layout of the building, the ventilation rate and room temperature, all of which are very variable. It is vital, therefore, that the heat losses are carefully estimated , even at the preliminary stage because this also determines the boiler rating, the chimney size, oil storage capacity and the general size of all auxiliary plant.

Even though the design is not detailed at the preliminary stage it is possible to use variables which represent the cost of chimneys and oil tanks; as they are a matched installation with the boilers it is possible to use the output of the boilers as the variable to represent them.

A pre-tender model whose accuracy was better than 10% would be a great asset to pre-tender cost planning, particularly if the time needed to estimate the tender figure was appreciably lower than that needed using current methods. Even if the accuracy was greater than 10% the saving in time may still be cost effective as the time (and money) saved on estimating may still be more than the loss in estimating efficiency. At worst, it would be a check method to conventional estimating techniques.

3. THE DERIVATION OF A HEATING COST MODEL FOR THE PRE-TENDER STAGE OF DESIGN

3.01. Conceptual Ideas on the Construction of the Model

Because large modern buildings are rarely repeated in their design and construction the layout of a piped heating scheme is invariably unique.

This leads to the situation whereby each heating scheme is individually tailored to the requirements of the building. There are also a great many designers spread among the institutions and companies who practise in heating design. This tends to the inevitable situation that the heating scheme of a building has inbuilt variability due to the building shape and to the personal contribution of the designer, as well as any special requirements of the owner.

The problem lies in finding the common denominator for all situations or to discover the magnitude of the many reasons for difference in design - and hence cost.

In this study the approach adopted initially is to use technical reasons to obtain a mean cost and to investigate the unexplained variance in terms of non-technical factors such as the type of designer.

In its most basic form a heating installation consists of a heat generator linked to a heat emission system. The generation of heat takes place in a boiler which is usually sited in a boiler room, and the heated water is piped to the emitters (radiators, convectors and space heaters) which are sited in the building to be heated.

A problem immediately arises because heating contracts do not always consist of both elements of the heating installation, the most common permutations being as follows :-

1. Emitters in a new building, supplied from boiler(s) sited within the building.
2. Emitters in a new building, supplied from boiler(s) in a remote boiler house.
3. Emitters in a new building, supplied from an existing boiler in a remote boiler house.
4. A boiler installation in a new boiler house.

The situation is further complicated when the contract consists of a part installation or the buildings housing the boiler(s) and emitters already exists and the contract consists of stripping out the existing installation and putting in a new system.

To overcome the problem of non-standarization of contracts it is necessary to consider the heating installation as two identifiable elements : a boiler house system and a building system.

Ignoring the cost of any pipework connecting the boiler house and the building the relationship between the cost and the content of the work is a s follows :-

$$\left.\begin{array}{c}\text{(COST OF BOILER HOUSE INSTALLATION)}\\ +\\ \text{(COST OF BUILDING INSTALLATION)}\end{array}\right\} = \left\{\begin{array}{c}\text{(FUNCTION OF BOILER TECHINCAL VARIABLES)}\\ +\\ \text{(FUNCTION OF BUILDING TECHNICAL VARIABLES)}\end{array}\right.$$

If one element is missing (say boiler house) in a particular contract, the equation reduces to:-

$$\text{(COST OF BUILDING INSTALLATION)} = \text{(FUNCTION OF BUILDING TECHNICAL VARIABLES)}$$

3.02 The Choice of Boiler House Technical Variables

The question to be answered is "what are the variables which always represent the cost of the boiler house plant?"

The answer revolves around the equipment in the boiler house and the factors which affect its cost.

Within a boiler house there are recognisable systems. For example, a boiler will have a fuel burning device, a flue, fuel pipes water pipes and electrical controls. All of these component parts are closely matched to the boiler and it is reasonable to assume that the size of the boiler (in terms of its kilowatt heat output) is the principal controlling factor on the price of the boiler installation.

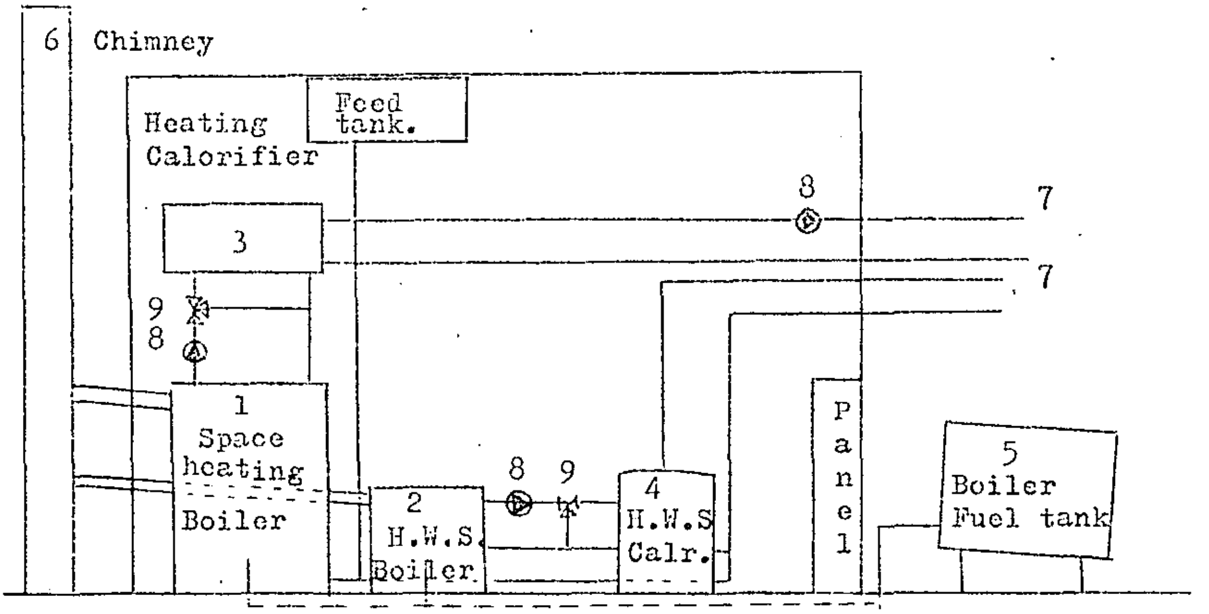
By the same reasoning it is possible to identify the principal component of all the systems within the boiler house, and by the use of a measurable size factor a representative value for the cost of each system in the boiler house can be obtained.

The variables chosen and the systems they represent are as follows :-

1. Heat Output (in kilowatts) and Number of Heating Boilers - to represent the generation of hot water for space heating purposes.
2. Heat Output (in kilowatts) and Number of Hot Water Service (HWS) Boilers - to represent the generation of hot water for domestic purposes.
3. Heat Output (in kilowatts) and Number of Heating Calorifiers to represent the exchange of heat to provide hot water for space heating purposes, when a heating calorifier is present.
4. Storage Capacity (in litres) and Number of Hot Water Service (H.W.S.) Calorifiers - to represent the storage of hot water for domestic purposes.
5. Storage Capacity (in litres) and Number of Boiler Fuel Tanks to represent the storage of fuel oil for the boilers.
6. The Number, Height (in metres) and Diameter (in millimetres) of the Chimneys - to represent the boiler effluent system external to the boiler house.

For a given Space Heating Boiler system the cost can also vary due to the complexity of the pipework and control system within the boiler house. To account for this effect three further variables can be used to quantify the influence of complexity in the pipework layout. They are :-

7. Number of Boiler House Flow Circuits.
8. Total Number of Heating Pumps and Hot Water Service Primary Circuit Pumps.
9. Number of 2 or 3-way Motorized Control Valves for the control of heating circuits and hot water service primary circuits.



There are other systems such as the boiler cold water feed, and the feed/expansion tank, which are of fairly low cost and can be deemed included within other systems such as the space heating and H.W.S. boilers and the space heating and H.W.S calorifiers.

The other major piece of equipment within the boiler house is the control panel and its outgoing wiring to the controls of the boilers, calorifiers, oil tank, pumps and valves. The cost of the panel and wiring can be considered as a charge to be spread between each of the systems that are controlled.

3.03 The Form of the Boiler House Technical Variables

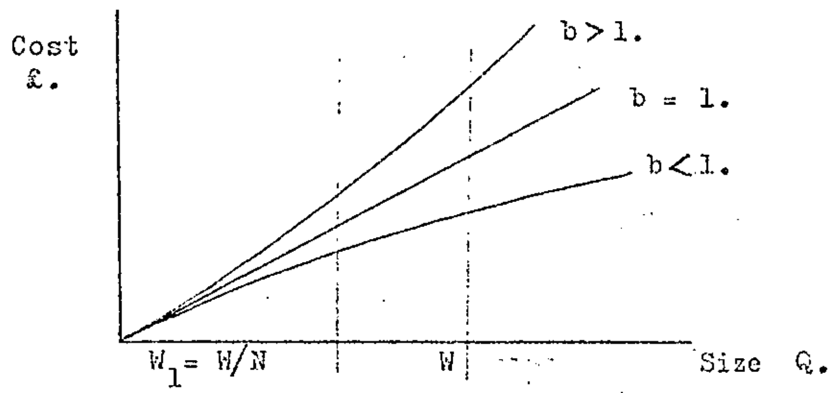
The theory postulated for the form of the variables is as follows:-

For the purchase of any given object the relationship between cost and magnitude could be approximated by the expression :-

$$\text{COST} \propto (\text{SIZE})^b$$

or $\text{COST} \propto (Q)^b$

It is generally the case that $b < 1$ for most products.



For a given size, say W, the cost of that quantity can be represented as follows :-

$$\text{COST} = C_1W^b \text{ where } C_1 \text{ is a constant}$$

Consider the quantity W split into N equal portions of size W/N (where $W/N = W_1$)

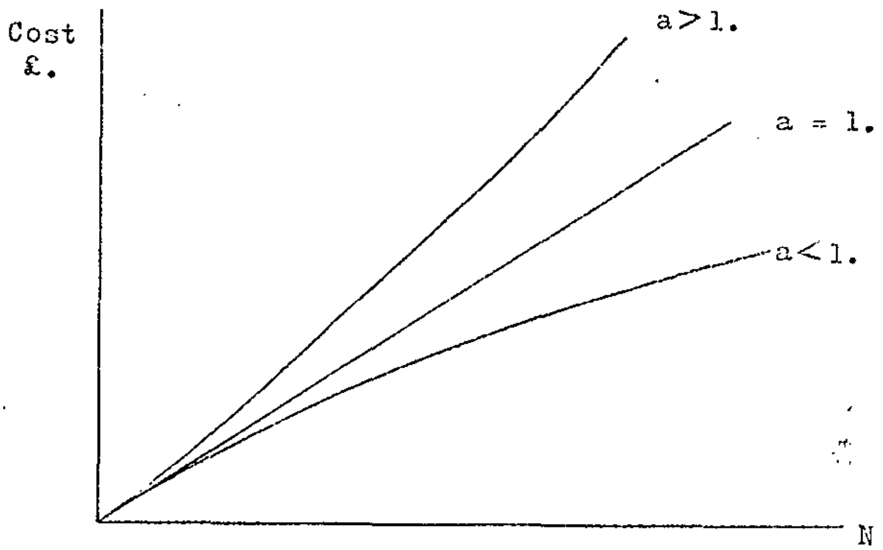
Each portion obeys the relationship $\text{COST} = C_1W_1^{\ b}$ and the total cost would be as follows

$$\text{COST} = NC_1(W/N)^b$$

However, the purchase and installation of N identical objects of size Q would be better expressed by the general case :-

$$\text{COST} \propto N^aQ^b \quad (Q=W/N)$$

It is generally the case that $a < 1$ to allow for discount rates on large purchases or for repetition work.



Hence,

$$COST = N^{a} C_1 (W/N)^{b}$$

$$\therefore COST = C_1 N^{a-b} W^{b}$$

$$\therefore COST = C_1 N^{d} W^{b} \qquad (d = a - b)$$

This expression lends itself to the boiler house variables because they can all be readily obtained in terms of a number and a quantity term. Thus for the boiler house it is possible to use the following expression :-

$$\text{BOILER HOUSE COST} \quad \sum_{p=1}^{p=p} C_p N_p^{d_p} W_p^{b_p}$$

This form of boiler house model does not lend itself to linear regression however, because the powers d_p and b_p are unknowns which cannot be obtained from a linear regression of the form :-

$$\text{BOILER HOUSE COST} = C_1 N_1^{d_1} W_1^{b_1} + \ldots\ldots\ldots\ldots\ldots + C_p N_p^{d_p} W_p^{b_p}$$

This is because the coefficients $C_1 \rightarrow C_p$ can only be obtained by regression.

It is necessary to arrive at the values of powers $d_1 \rightarrow d_p$ and $b_1 \rightarrow b_p$ in some other way.

Fortunately P.S.A. contracts sometimes contain a summary of tender in which the costs of the space heating boilers, H.W.S. calorifiers, oil tanks and chimneys are given as separate items.

This allows the expression $COST_p = C_p N_p^{d_p} W_p^{b_p}$ to be examined in isolation as follows :-

If $COST_p = C_p N_p^{d_p} W^{b_p}$

Then $\log_{10} COST_p = \log_{10} C_p + d_p \log_{10} N_p + b_p \log_{10} W_p$

i.e. $y = A + Bx + Cz$

which is a multiple linear expression for which a regression trial can be conducted in order to find the values of A, B and C (Hence C_p, d_p and b_p)

Of the 6 principal components of the Boiler House namely Space Heating Boilers, H.W.S. Boilers, Space Heating Calorifiers, H.W.S. Calorifiers, Oil Tanks and Chimneys the values for d_p and b_p could be established for Space Heating Boilers, H.W.S. Calorifiers, Oil Tanks and Chimneys. (because costs were available)

Although values for H.W.S. Boilers and Space Heating Calorifiers could not be obtained through lack of data it can be argued that in the case of H.W.S. Boilers it is permissable to use the values of d_p and b_p found for space heating boilers, as the H.W.S. boilers are usually smaller versions of those used for space heating purposes. In the case of space heating calorifiers it is not so easy to make a comparison. Nevertheless, because a space heating calorifier is a constant flow device it can be likened to a boiler, and because it assumes the role of a boiler it could be assumed that the values of d_p and b_p for space heating boilers could apply to space heating calorifiers.

In the case of the 3 subsidiary components : circuits, pumps and valves, cost is not proportional to number alone. It can be argued that the size of the circuit pipework, the pumps and the valves grows in the same proportion as the heating system they control. Thus it could be reasonably assumed that the cost of the circuits, pumps and valves has a relationship of the form :-

COST = $C_p N_p W_p^{b_p}$ (where $W_p^{b_p}$ is the heat output of the heating system).

The complete objective function for the boiler house is then as follows :-

BOILER HOUSE COST =	$C_1 N_1^{d_1} W_1^{b_1}$	SPACE HEATING BOILERS
	$+ C_2 N_2^{d_1} W_2^{b_1}$	H.W.S. BOILERS
	$+ C_3 N_3^{d_1} W_3^{b_1}$	SPACE HEATING CALORIFIERS
	$+ C_4 N_4^{d_4} W_4^{b_4}$	H.W.S. CALORIFIERS
	$+ C_5 N_5^{d_5} W_5^{b_5}$	OIL FUEL TANKS
	$+ C_6 N_6^{d_6} W_6^{b_6}$	CHIMNEYS
	$+ C_7 N_7 W_1^{b_1}$	BOILER HOUSE CIRCUITS
	$+ C_8 N_8 W_1^{b_1}$	BOILER HOUSE PUMPS
	$+ C_9 N_9 W_1^{b_1}$	BOILER HOUSE VALVES

3.04 The Form of the Building Technical Variables

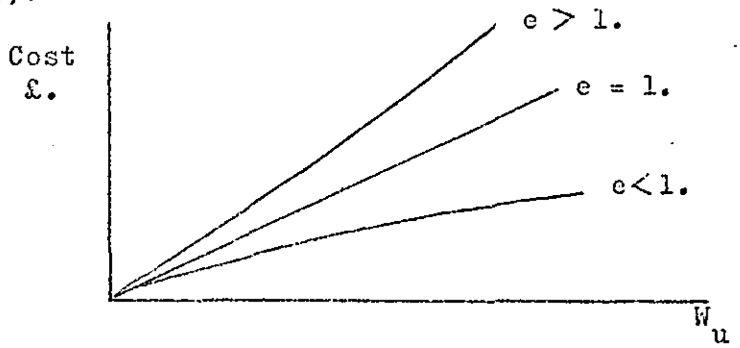
Within a building the heating system consists of distributing pipework to the various emitters (such as radiators)controlled by circuit control valves, with pumps for water circulation.

The size of these components is governed, to a large extent, by the amount of water that has to be circulated in order to bring the designed amount of heat to the emitters. The amount of water is related to the amount of heat to be supplied and thus it can be said that the following expression is a reasonable approximation to the cost of the heating system in the building :-

$COST \propto W_u^e$ (where W_u is the amount of heat to be supplied to the building i.e. the BUILDING HEAT LOSSES.)

or $COST = f_o W_u^e$ (f_o is a constant).

The power 'e' is included as it can reasonably assumed that there is a power relationship between Cost and W_u (not unlike the boiler house).

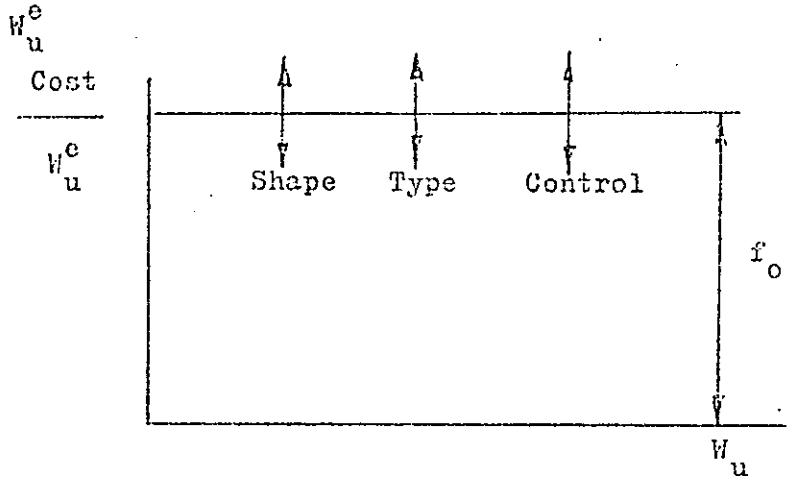


For any building of a given heat loss the design is unique and the amount of money needed to comply with the particular specification for a building could vary according to the size of the rooms, the shape of the building, the number of rooms, the type of heating installation and the control method.

Thus the cost could vary according to the Building SHAPE & TYPE and the CONTROL of the heating system.

Using the expression $COST = f_o W_u^e$ in the re-arranged form $COST/W_u^e = f_o$ it is possible to conclude that for any building of heat loss W_u the dependent variable $COST/W_u^e$ is modified by SHAPE, TYPE or CONTROL factors in the following manner :-

$$\frac{\text{BUILDING COST}}{W_u^e} = f_o \left(1 + \text{SHAPE VARIABLES} + \text{TYPE VARIABLES} + \text{CONTROL VARIABLES}\right)$$



SHAPE variables could include the size and number of rooms, the floor area, the volume, storey height, total height or any derivations of these variables.

TYPE variables include the 8 different types of piped heating systems covered by this study.

CONTROL variables could include the number of PUMPS and CONTROL valves in the building.

The objective function for building cost thus becomes :-

$$\frac{\text{BUILDING COST}}{W_u^e} = f_o + f_1 \left(\frac{\text{FLOOR AREA OF ROOMS}}{\text{NUMBER OF ROOMS}}\right)$$

$$+ f_2 \left(\frac{\text{VOLUME OF ROOMS}}{\text{FLOOR AREA OF ROOMS}}\right)$$

$$+ f_3 \left(\begin{array}{l}\text{PERCENTAGE OF HEAT} \\ \text{BY HEATING TYPE 1.}\end{array}\right)$$

$$+ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

$$+ f_{10} \left(\begin{array}{l}\text{PERCENTAGE OF HEAT} \\ \text{BY HEATING TYPE 8}\end{array}\right)$$

$$+ f_{11} \left(\text{NUMBER OF PUMPS IN THE BUILDING}\right)$$

$$+ f_{12} \left(\text{NUMBER OF VALVES IN THE BUILDING}\right)$$

In the case of heating types 1 to 8 it is frequently the case that several types occur together and so these terms need to be modified to include for this fact. This can be achieved by making 'heating types 1 → 8' become percentage of heat by types 1 → 8.

The value of e can be found from a regression involving BUILDING COST and W_u in the following way :-

BUILDING COST = $f_o W_u^e$

$\log_{10}$ BUILDING COST = $\log_{10} f_o + e \log_{10} W_u$

i.e. $Y = A + Bx$

which is a multiple linear regression for which a regression can be conducted in order to find the values of A & B (hence f_o and e).

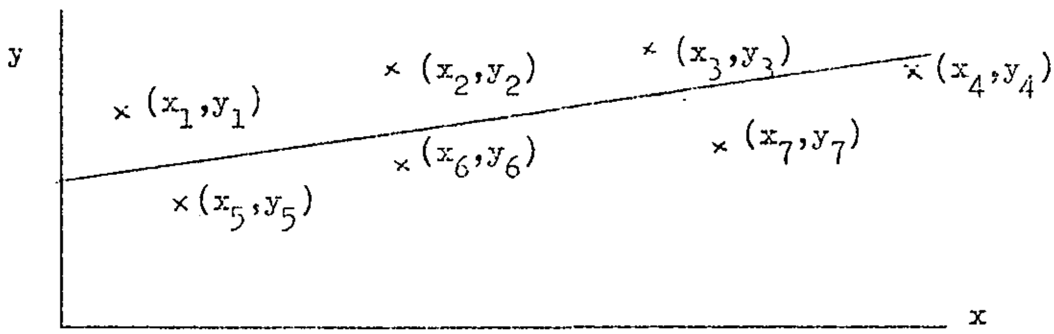
3.05 The Total Technical Model

Total Cost of the Boiler House and Building Installations (by technical reasoning alone) can be obtained by adding the BOILER HOUSE COST to the BUILDING COST to achieve the following objective function :-

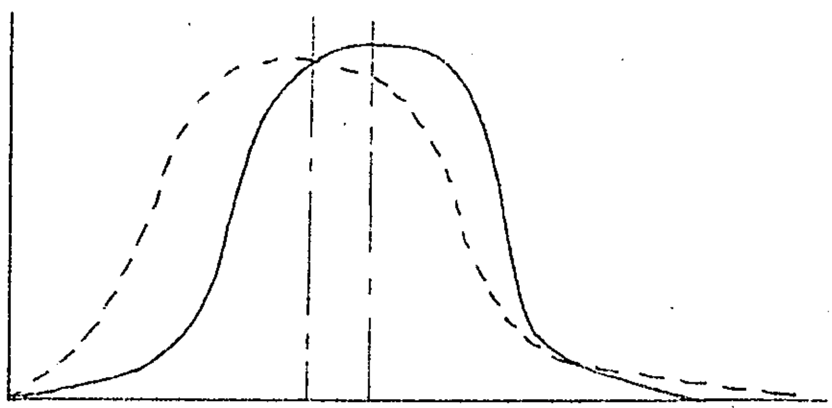
$$
\begin{array}{lll}
\text{TOTAL COST} = & g_0 W_u^e & \\
+ & g_1 W_u^e \left(\dfrac{\text{FLOOR AREA OF ROOMS}}{\text{NUMBER OF ROOMS}} \right) & \\
+ & g_2 W_u^e \left(\dfrac{\text{VOLUME OF ROOMS}}{\text{FLOOR AREA OF ROOMS}} \right) & \text{SHAPE} \\
+ & g_3 W_u^e \ (\text{PERCENTAGE OF HEAT BY TYPE 1}) & \\
+ & \cdots\cdots & \text{TYPE} \\
+ & g_{10} W_u^e \ (\text{PERCENTAGE OF HEAT BY TYPE 8}) & \\
+ & g_{11} W_u^e \ (\text{NUMBER OF PUMPS IN THE BUILDING}) & \text{CONTROL} \\
+ & g_{12} W_u^e \ (\text{NUMBER OF VALVES IN THE BUILDING}) & \\
+ & g_{13} N_1^{d_1} W_1^{b_1} & \text{SPACE HEATING BOILERS} \\
+ & g_{14} N_2^{d_1} W_2^{b_1} & \text{H.W.S. BOILERS} \\
+ & g_{15} N_3^{d_1} W_3^{b_1} & \text{SPACE HEATING CALORIFIERS} \\
+ & g_{16} N_4^{d_4} W_4^{b_4} & \text{H.W.S. CALORIFIERS} \\
+ & g_{17} N_5^{d_5} W_5^{b_5} & \text{OIL FUEL TANKS} \\
+ & g_{18} N_6^{d_6} W_6^{b_6} & \text{CHIMNEYS} \\
+ & g_{19} N_7 \ W_1^{b_1} & \text{BOILER HOUSE CIRCUITS} \\
+ & g_{20} N_8 \ W_1^{b_1} & \text{BOILER HOUSE PUMPS} \\
+ & g_{21} N_9 \ W_1^{b_1} & \text{BOILER HOUSE VALVES}
\end{array}
$$

3.06 WEIGHTING ADJUSTMENT

3.06. 1. In linear regression analysis one of the failings of the technique is the tendency for errors to occur due to 'scale' effects e.g. in the figure below the large values of $(x_4\ y_4)$ would cause a regression to fit well to the point $(x_4\ y_4)$ because it is an isolated value at the upper extreme of the scale. This can be extremely misleading because the values of x_4 and y_4 may have a high random error, and be highly influential in its effect on the regression line.

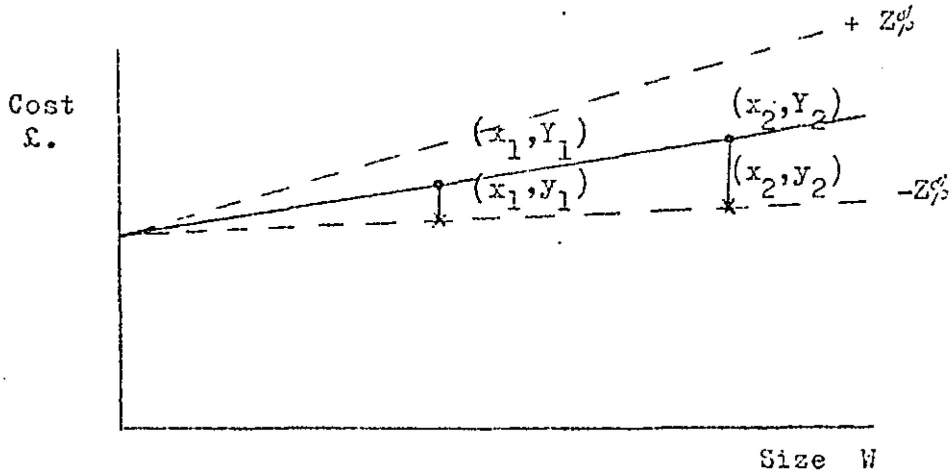


The data obtained for a regression trial often has a 'skewed' distribution rather than a 'normal' distribution as shown below.



This could result in a few large sized values in the sample having a disproportionate effect on the formation of the regression line.

3.06. 2. For a given series of contracts it is reasonable to assume that the level of estimating accuracy is relatively constant. (Although small contracts are more difficult to estimate accurately).



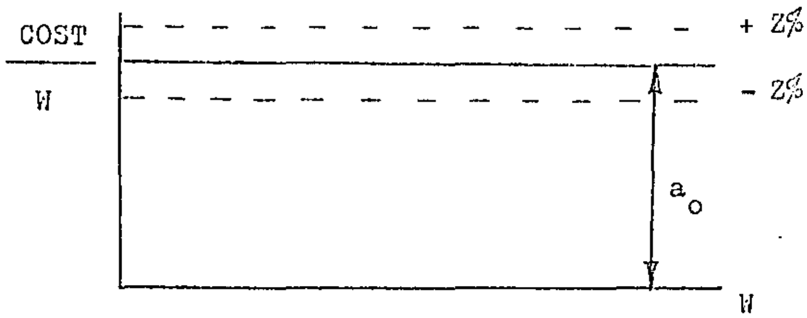
The above figure demonstrates the zone into which one would expect the cost of contracts to fall i.e.

COST = SIZE FACTOR ± Z%

It can be seen that $(Y_2 - y_2)^2$ is very much greater than $(Y_1 - y_1)^2$ and that the effect is for large contracts to have a very much greater influence on the regression line than small contracts

The way to eliminate the influence of large contracts is to weight each contract equally. This can be done by employing the device already employed in Section 3.04 i.e. if COST = $f_o W_u^e$ then :-

$$\frac{COST}{W_u^e} = f_o \text{ (for all values of } W_u)$$



3.06.3. Consider COST (Boiler House) = $BW_1^{b_1}$
and COST (Building) = CW_u^e as being approximate expressions for the two component parts of the Total Cost Model.

Then TOTAL COST = $BW_1^{b_1} + CW_u^e$

$$\text{or } \frac{\text{TOTAL COST}}{(W_1^{b_1} + \frac{C}{B} W_u^e)} = B \text{ .... (1)}$$

3.06. 4. In equation (1) the term $\dfrac{\text{TOTAL COST}}{(W_1^{b_1} + \frac{C}{B} W_u^e)}$ provides a reasonable approximation to the value of the dependent variable which gives equal weighting to all contracts.

The ratio C/B is readily available from the regression trials on the models :-

$$\log_{10} (\text{Boiler Cost}) = \log_{10} B + b_1 \log_{10} W_1$$

and $$\log_{10} (\text{Building Cost}) = \log_{10} C + e \log_{10} W_u$$

The term $(W_1^{b_1} + \frac{C}{B} W_u^e)$ is named the MAGNITUDE FACTOR (MF)

For the Total Technical Model on Page 18 :-

$$\frac{\text{TOTAL COST}}{MF} = \frac{g_o W_u^e}{MF} + \ldots\ldots\ldots\ldots\ldots + \frac{g_{21} N_9 W_1^{b_1}}{MF} \quad \ldots\ldots(1)$$

3.07 Economic Variables

So far only the effect of technical factors on cost has been considered. In practice there are other variables which could have some bearing on cost and these have been termed 'economic variables'. They include the number of tenders invited, the percentage of invitations returned, the location of the building site, the designer of the installation, the date of tender, the contract period, whether the installation is in a new or existing building, whether the contract is a sub-contract to a main building contract or a direct contract with the specialist heating contractor, the distance from the site to the contractors office and the type of building e.g. offices, workshops.

The economic factors can be considered as multiplying factors which add to or subtract from the cost due to technical factors alone.

Thus the expression for cost could be as follows :-

$$\text{TOTAL COST} = \left(\begin{array}{l}\text{FUNCTION OF}\\ \text{TECHNICAL VARIABLES}\end{array}\right) + \left(\begin{array}{l}\text{FUNCTION OF}\\ \text{TECHNICAL VARIABLES}\end{array}\right) \times \left(\begin{array}{l}\text{FUNCTION OF}\\ \text{ECONOMIC VARIABLES}\end{array}\right)$$

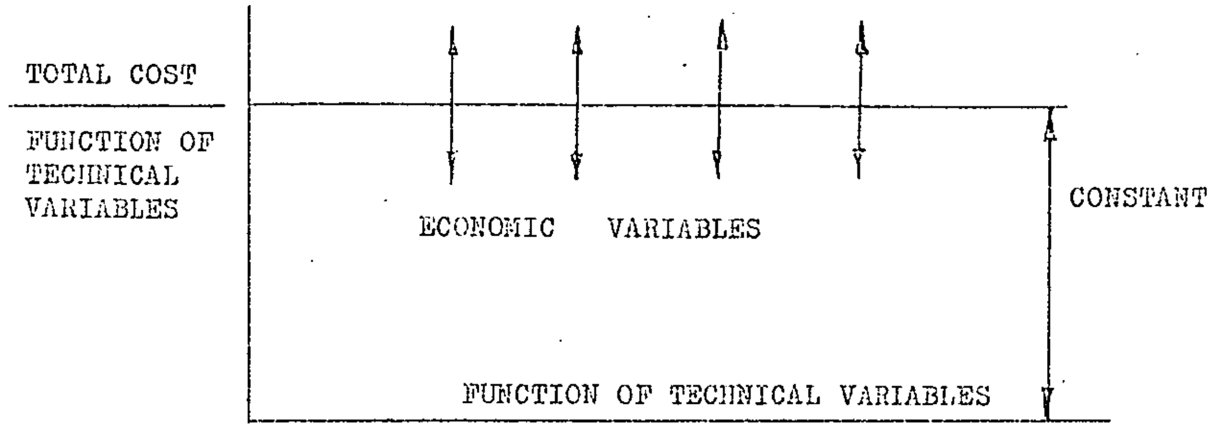
Rearranging this expression :-

$$\frac{\text{TOTAL COST}}{\left(\begin{array}{l}\text{FUNCTION OF}\\ \text{TECHNICAL VARIABLES}\end{array}\right)} = \text{CONSTANT} + \left\{\begin{array}{l}\text{FUNCTION OF}\\ \text{ECONOMIC VARIABLES}\end{array}\right\}$$

This way of expressing the dependent variable has the advantage of making the dependent variable a minimum and gives each contract more equal weight.

It also allows economic variables to be added in simple linear form, which makes the regression easy to operate.

Having found the coefficients for the best technical model it is possible to divide TOTAL COST by the best model in technical variables to give a model in economic variables.



The TOTAL MODEL WITH ECONOMIC VARIABLES would be as follows :-

$$
\begin{aligned}
\frac{\text{TOTAL COST}}{\left(\begin{array}{l}\text{FUNCTION OF}\\ \text{TECHNICAL VARIABLES}\end{array}\right)} = h_o &+ h_1 \ (\text{Contract Period}) \\
&+ h_2 \left(\frac{\text{Number of tenders returned}}{\text{Number of tenders invited}}\right) \\
&+ h_3 \ (\text{Site location 1}) \\
&+ \ldots\ldots\ldots\ldots\ldots\ldots \\
&+ h_{12} \ (\text{Site location 10}) \\
&+ h_{13} \ (\text{Designer 1}) \\
&+ h_{14} \ (\text{Designer 2}) \\
&+ h_{15} \ (\text{Designer 3}) \\
&+ h_{16} \ (\text{Type of building 1}) \\
&+ \ldots\ldots\ldots\ldots\ldots\ldots \\
&+ h_{23} \ (\text{Type of building 8}) \\
&+ h_{24} \ (\text{New boiler house}) \\
&+ h_{25} \ (\text{New building}) \\
&+ h_{26} \ (\text{Sub-Contract}) \\
&+ h_{27} \ (\text{Distance from site to Contractors office}) \\
&+ h_{28} \ (\text{Distance from site to nearest town of 75,000 inhabitants}) \\
&+ \frac{h_{29}}{366} \ (\text{Number of days from 1.1.72 to date of tender acceptance})
\end{aligned}
$$

For derived variables 3 to 26 the value of the raw variable is 1 or 0 i.e. a 'dummy' value where the numeral 1 signifies that the variable is applicable and the numeral 0 where it is not so.

4. THE RESULTS OF THE COMPUTER ANALYSES FOR THE PRE-TENDER STAGE MODEL.

4.01. In order to build up the model into its final form consisting of boiler house technical variables, building technical variables and economic variables a start was made on the determination of the boiler house system variables for :-

a. Space Heating Boilers

b. H.W.S. Boilers

c. Space Heating Calorifiers

d. H.W.S. Calorifiers

e. Oil Fuel Tanks

f. Chimneys

4.02. Space Heating Boilers

The DOE standard method of lump-sum tendering provides 'system' costs for most contracts and this data was used to determine the powers d_p and b_p in the expression :

$COST = C_1 N_1^{d_1} W_1^{b_1}$ where W_1 is the total heat output of the boilers and N_1 the number of boilers.

by taking logarithms :

$$\log_{10}(COST) = \log_{10}(C_1) + d_1 \log_{10}(N_1) + b_1 \log_{10}(W_1)$$

Carrying out a regression with the cost data and corresponding data for N and W gave $d_1 = 0.2$ and $b_1 = 0.55$ (To the nearest 0.05).

In statistical terms both N_1 and W_1 were highly significant variables, supporting the approach adopted.

4.03 H.W.S. Boilers

When domestic hot water is provided from a self-contained boiler it is not always possible to determine the system cost from the summary of tender. Consequently separate trials to find values of d and b were not possible.

As H.W.S. boilers are usually similar in manufacture to space heating system boilers and the hydraulic arrangements are comparable the same values of d and b as were obtained for heating system boilers were used for the H.W.S. boilers.

4.04 Space Heating Calorifiers

The same line of argument was used for space heating calorifiers. Although non-storage heating calorifiers are not such a good subject for comparison with space heating boilers the operation of the hydraulic system is similar and gives a reasonable basis for using the values of d and b found for space heating boilers.

4.05 H.W.S. Calorifiers

H.W.S. storage calorifiers are different in design and operation from boilers, which requiredthat appropriate values of d and b be found. Although data was scarce it was possible to establish that the quantity of hot water storage was a significant variable and that $b_4 = 0.25$. The number of calorifiers was found to be insignificant.

4.06 Oil Fuel Tanks

A reasonable amount of data was available for oil fuel tanks from which it was possible to determine that $d_5 = 0.5$ and $b_5 = 0.5$; the storage capacity of the tanks being the quantity variable.

4.07 Chimneys

For chimneys the cost is dependent upon the amount of metal used (the surface area) and the number.

Regression established the following relationship :-

COST $N_6^{0.9} W_6^{0.9}$, where W_6 is the surface area per chimney and N_6 the number of chimneys.

4.08 Boiler House Pumps, Valves and Pipe Circuits

The cost of a boiler house varies considerably with the number of circuits being fed. These may arise from the need to supply several buildings or several circuits within a building. Some circuits have separate pumps and three way valves, others not. The variables used to represent the cost of this complexity was the product of the number of pumps, valves or circuits and the total kilowatts output of the space heating boilers in the boiler house. For buildings supplied by space heating calorifier the output of the calorifiers was used and for buildings with only an incoming heating main the heat requirement of the building was adopted :

i.e. N Pumps ($W_1^{0.5}$ or $W_3^{0.55}$ or $W_u^{0.55}$)

+ N Valves ($W_1^{0.5}$ or $W_3^{0.55}$ or $W_u^{0.55}$)

+ N Circuits ($W_1^{0.5}$ or $W_3^{0.55}$ or $W_u^{0.55}$)

The variables $W_1^{0.5}$ was eventually adopted to compensate for the value of W_1 usually being greater than W_3 or W_u due to mains heat losses.

4.09 <u>The Total Technical Model</u>

The expression (1) in 3.06.4 was used to determine the best technical model, the magnitude factor (MF) being taken as $W_1^{0.55} + 0.18W_u^{0.85}$

The regression equation which gave the lowest standard error of the variables in the regression was as follows :-

$$\frac{\text{TOTAL COST}}{MF} = \frac{57.60917}{MF} W_u^{0.85} \quad \text{BUILDING HEAT LOSS}$$

$$+ \frac{24.30901}{MF} (\text{\% of heat by continuous convectors}) \; W_u^{0.85}$$

$$+ \frac{106.94150}{MF} (\text{\% of heat by skirting convectors}) \; W_u^{0.85}$$

$$+ \frac{32.81960}{MF} (\text{\% of heat by radiant panels}) \; W_u^{0.85}$$

$$- \frac{28.39179}{MF} (\text{\% of heat by unit heaters}) \; W_u^{0.85}$$

$$- \frac{53.94303}{MF} (\text{\% of heat by fan convectors}) \; W_u^{0.85}$$

$$+ \frac{3.88239}{MF} (\text{Number of pumps in the building}) \; W_u^{0.85}$$

$$+ \frac{171.99084}{MF} \left(N_1^{0.2}\, W_1^{0.55}\right)$$ SPACE HEATING BOILERS

$$+ \frac{229.84913}{MF} \left(N_3^{0.2}\, W_3^{0.55}\right)$$ SPACE HEATING CALORIFIERS

$$+ \frac{404.87226}{MF} \left(W_4^{0.25}\right)$$ H.W.S. CALORIFIERS

$$+ \frac{5.87032}{MF} \left(N_5^{0.5}\, W_5^{0.5}\right)$$ OIL FUEL TANKS

$$+ \frac{0.33238}{MF} \left(N_6^{0.9}\, W_6^{0.9}\right)$$ CHIMNEYS

$$+ \frac{6.19710}{MF} (N_7)\left(W_1^{0.5} \text{ or } W_3^{0.55} \text{ or } W_u^{0.55}\right)$$ BOILER HOUSE CIRCUITS

$$+ \frac{11.62477}{MF} (N_8)\left(W_1^{0.5} \text{ or } W_3^{0.55} \text{ or } W_u^{0.55}\right)$$ BOILER HOUSE PUMPS

Multiplying through MF gives the cost of the heating installation in terms of the technical variables.

The coefficient of variation of the model expressed as the standard error of the model divided by the mean value of the dependent variable was 27.7%

4.10. The Total Model with Economic Variables

From the total technical model the total model with economic variables was developed.

$$\text{TOTAL COST} = \left(\begin{array}{l}\text{FUNCTION OF}\\ \text{TECHNICAL VARIABLES}\end{array}\right) + \left(\begin{array}{l}\text{FUNCTION OF}\\ \text{TECHNICAL VARIABLES}\end{array}\right) \times \left(\begin{array}{l}\text{FUNCTION OF}\\ \text{ECONOMIC VARIABLES}\end{array}\right)$$

or

$$\frac{\text{TOTAL COST}}{\left(\begin{array}{l}\text{FUNCTION OF}\\ \text{TECHNICAL VARIABLES}\end{array}\right)} = \text{CONSTANT} + \left(\begin{array}{l}\text{FUNCTION OF}\\ \text{ECONOMIC VARIABLES}\end{array}\right)$$

The regression tried was as follows :-

$$
\begin{aligned}
\underline{\text{TOTAL COST}} \\
\text{(Model 4.09)} \quad = \quad & h_o + h_1 \text{ (London)} \\
& + h_2 \text{ (North West)} \\
& + h_3 \text{ (Midlands)} \\
& + h_4 \text{ (South West)} \\
& + h_5 \text{ (South East)} \\
& + h_6 \text{ (South)} \\
& + h_7 \text{ (North East)} \\
& + h_8 \text{ (Provinces)} \\
& + h_9 \text{(Wales)} \\
& + h_{10} \text{(Scotland)} \\
& + \frac{h_{11}}{366} \text{(No. of days from 1st Jan 1972 to date of tender acceptance)} \\
& + h_{12} \text{(Contract period)} \\
& + h_{13} \text{(Offices)} \\
& + h_{14} \text{(Workshops)} \\
& + h_{15} \text{(Laboratories)} \\
& + h_{16} \text{(Telphone Exchange)} \\
& + h_{17} \text{(Hangar)} \\
& + h_{18} \text{(Sorting Office)} \\
& + h_{19} \text{(Post Office)} \\
& + h_{20} \text{(Domestic Accommodation)} \\
& + h_{21} \text{(New Boiler House Installation)} \\
& + h_{22} \text{(New Building Installation)} \\
& + h_{23} \text{(Sub-Contract)} \\
& + h_{24} \text{(P.S.A./D.O.E. Design)} \\
& + h_{25} \text{(Consultants Design)} \\
& + h_{26} \text{(Contractors Design)}
\end{aligned}
$$

$+ \; h_{27}$(No. of tenders received/No.of tenders invited).

$+ \; h_{28}$(Distance from site to Contractors Office)

$+ \; h_{29}$(Distance from site to nearest town of 75,000 inhabitants)

The variables h_1 to h_{10} were included to indicate regional variations in price, h_{11} to take account of inflation during the period over which the contracts were let and h_{12} the effect of inflation during the duration of the contract.

h_{13} to h_{20} took into account the different types of building, h_{21} and h_{22} the result of installing the heating system concurrently with the construction of the building and boiler house. h_{23} involved the type of contract whilst h_{24}, h_{25} and h_{26} gauged the effect of the designer.

h_{27} was an attempt to measure the tendering climate. h_{28} took into account the remoteness of the site for general travelling and material deliveries, whilst h_{29} was included for daily travelling by operatives.

The regression equation which gave the lowest standard error of the variables in the regression was as follows :-

$$\frac{\text{TOTAL COST}}{\text{(Technical Model 4.09)}} = 0.76116 + 0.19013\,(\text{London}) - 0.09787\,(\text{North West}) - 0.09337\,(\text{Midlands}) + \frac{0.16413}{366}\,(\text{Number of days from 1.1.72}) + 0.00871\,(\text{Contract Period}) + 0.29583\,(\text{Sorting Office}) + 0.10646\,(\text{Consultants})$$

The coefficient of variation of the model measured as the standard error of the model divided by the mean value of the dependent variable, expressed as a percentage was 22.00%

5. THE DERIVATION OF A HEATING COST MODEL FOR THE PRELIMINARY SKETCH PLAN STAGE OF DESIGN

5.01 Conceptual Ideas on the Construction of the Model

In principle the construction of the model follows the pattern of the pre-tender model.

```
TOTAL COST      =  (FUNCTION OF BOILER HOUSE & BUILDING)
(Boiler House)     (TECHNICAL VARIABLES                )
(& Building  )
                                   +
                   (FUNCTION OF BOILER HOUSE & BUILDING)
                   (TECHNICAL VARIABLES                )
                x  (FUNCTION OF ECONOMIC VARIABLES )
```

The difference between the two models lies in the choice of variables. At preliminary sketch plan stage there are less details known about the installation and the form of the variables has to take account of this situation.

5.02 The Choice of Boiler House Technical Variables

At preliminary sketch plan stage it is possible to calculate the heat losses of the building and hence to state the number and size of heating boilers to satisfy the demand. Thus the heat output of the heating boilers is a suitable variable to represent the generation of hot water for space heating purposes.

For buildings heated by space heating calorifiers the required heat output of the calorifiers can be stated and used to represent this type of system.

For the domestic hot water service the kW rating of the H.W.S. boiler and the capacity of the H.W.S. calorifier can be used to represent the cost. (As the data collected for this work includ ed the cost of the H.W.S. System on many contracts, and this cost could not always be isolated from the cost of the space heating service, the variables for H.W.S. equipment used in this model are the same as those for the pre-tender model so that the accuracy of the model is least affected).

At preliminary stage the oil tank storage capacity may not be known. The cost of oil storage is therefore represented by the heat output of the space heating boilers, as the amount of oil stored is usually related to the rate of use by these boilers.

The chimney cost is represented by the number of space heating boilers and the total capacity of space heating boilers, together with the number of chimneys.

From the pre-tender model the number of heating pumps and the number of boiler house flow circuits were found to be significant variables. These are included in this model.

At this stage of design the numbers of boilers, oil tanks pumps and circuits are not firm. Changes in the design of the heating system to suit the final design of the building may cause initial design decisions to be reconsidered and amended. However, with this form of model the Engineer will be able to assess the financial result of design changes which affect the numbers of principal system components.

The complete objective function for the boiler house is then as follows :-

$$
\begin{aligned}
\text{BOILER HOUSE COST} &= C_1 N_1^{d_1} W_1^{b_1} && \text{SPACE HEATING BOILERS} \\
&+ C_2 W_2^{b_1} && \text{H.W.S. BOILERS} \\
&+ C_3 N_3^{d_1} W_3^{b_1} && \text{SPACE HEATING CALORIFIERS} \\
&+ C_4 W_4^{b_4} && \text{H.W.S. CALORIFIERS} \\
&+ C_5 (N_5 N_1 W_1)^{b_5} && \text{CHIMNEYS} \\
&+ C_6 N_6^{d_6} W_1^{b_1} && \text{OIL FUEL TANKS} \\
&+ C_7 N_7 W_1^{b_1} && \text{BOILER HOUSE CIRCUITS} \\
&+ C_8 N_8 W_1^{b_1} && \text{BOILER HOUSE PUMPS}
\end{aligned}
$$

Having had the benefit of the pre-tender analysis the effect of boiler house motorized valves on the model had been insignificant and the derived term for valves had been statistically outside the 95% confidence limits. It was therefore left out of the preliminary model.

5.03 The Choice of Building Variables

From the building model at pre-tender stage the derived variables involving building heat loss and type of system were found to be most important.

As this information would be available to the designer at preliminary design stage by virtue of his calculations of heat loss and by his choice of design system the derived variables to represent building cost were as follows :-

$$\begin{aligned}\text{BUILDING COST} = \; & f_o W_u^e + f_1 (\text{\% of heat by continuous convectors}) W_u^e \\ & + f_2 (\text{\% of heat by radiant panels}) W_u^e \\ & + f_3 (\text{\%of heat by unit heaters}) W_u^e \\ & + f_4 (\text{\%of heat by fan convectors}) W_u^e \\ & + f_5 (\text{\%of heat by skirting convectors}) W_u^e \\ & + f_6 (\text{\% of heat by radiators}) W_u^e \\ & + f_7 (\text{\% of heat by natural convectors}) W_u^e \\ & + f_8 (\text{\% of heat by pipe coils}) W_u^e\end{aligned}$$

The term involving the number of pumps in the building was not included as the designer would not be able to give a reasonable estimate at preliminary design stage. From the pre-tender stage model its statistical significance was low (f value less than 2) and its contribution to the cost of the building installation less than $2\frac{1}{2}$%.

5.04 The Total Technical Model

As with the pre-tender model the derived technical variables for boiler house and buildings were combined and subjected to the weighting adjustment to give the following expression :-

$$\frac{\text{TOTAL COST}}{\text{MF}} = \frac{\text{FUNCTION OF BOILER HOUSE AND BUILDING TECHNICAL VARIABLES}}{\text{MF}}$$

5.05 The Total Model with Economic Variables

After obtaining the best model in technical variables alone the effect of Economic Variables is introduced in the following expression :-

$$\frac{\text{TOTAL COST}}{\left(\text{FUNCTION OF TECHNICAL VARIABLES}\right)} = \left(\text{CONSTANT}\right) + \left(\text{FUNCTION OF ECONOMIC VARIABLES}\right)$$

6. THE RESULTS OF THE COMPUTER ANALYSIS FOR THE PRELIMINARY STAGE MODEL

6.01. The Technical Model

Using the technical models for the building and boiler house (5.02 & 5.03) combined to give model 5.04, the model which gave the lowest standard error was as follows :-

$$\frac{\text{TOTAL COST}}{\text{MF}} = \frac{59.95960}{\text{MF}}\left(W_u^{0.85}\right) \quad \text{BUILDING HEAT LOSS}$$

$$+ \frac{25.00131}{\text{MF}}(\text{\% of heat by continuous convectors})W_u^{0.85}$$

$$+ \frac{33.26266}{\text{MF}}(\text{\% of heat by radiant panels})W_u^{0.85}$$

$$- \frac{28.69273}{\text{MF}}(\text{\% of heat by unit heaters})W_u^{0.85}$$

$$- \frac{53.41300}{\text{MF}}(\text{\% of heat by fan convectors})W_u^{0.85}$$

$$+ \frac{101.84609}{\text{MF}}(\text{\% of heat by skirting convectors})W_u^{0.85}$$

$$+ \frac{172.66727}{\text{MF}}\left(N_1^{0.2}\ W_1^{0.55}\right) \quad \text{SPACE HEATING BOILERS}$$

$$+ \frac{231.17664}{\text{MF}}\left(N_3^{0.2}\ W_3^{0.55}\right) \quad \text{SPACE HEATING CALORIFIERS}$$

$$+ \frac{401.92386}{\text{MF}}\left(W_4^{0.25}\right) \quad \text{H.W.S. CALORIFIERS}$$

$$+ \frac{57.47639}{\text{MF}}\left(N_5 N_1 W_1\right)^{0.3333} \quad \text{CHIMNEYS}$$

$$+ \frac{25.18146}{\text{MF}}\left(N_6^{0.5}\ W_1^{0.55}\right) \quad \text{OIL FUEL TANKS}$$

$$+ \frac{5.87149}{\text{MF}}\left(N_7\right)\left(W_1^{0.55} \text{ or } W_3^{0.55} \text{ or } W_u^{0.55}\right) \quad \text{BOILER HOUSE CIRCUITS}$$

$$+ \frac{7.96547}{\text{MF}}\left(N_8\right)\left(W_1^{0.55} \text{ or } W_3^{0.55} \text{ or } W_u^{0.55}\right) \quad \text{BOILER HOUSE PUMPS}$$

The coefficient of variation of the model, measured as the standard error of the model divided by the mean value of the dependent variable and expressed as a percentage was 28%.

Multiplying through(MF) gives the cost in terms of technical variables alone.

6.02 The Total Model with Economic Variables

From the technical model the full model with economic variables was developed.

$$\text{COST} = \begin{pmatrix}\text{FUNCTION OF} \\ \text{TECHNICAL VARIABLES}\end{pmatrix} + \begin{pmatrix}\text{FUNCTION OF} \\ \text{TECHNICAL VARIABLES}\end{pmatrix} \times \begin{pmatrix}\text{FUNCTION OF} \\ \text{ECONOMIC VARIABLES}\end{pmatrix}$$

$$\text{or } \frac{\text{COST}}{\begin{pmatrix}\text{FUNCTION OF} \\ \text{TECHNICAL VARIABLES}\end{pmatrix}} = \text{CONSTANT} + \begin{pmatrix}\text{FUNCTION OF} \\ \text{ECONOMIC VARIABLES}\end{pmatrix}$$

The regression tried was as follows :-

$$\begin{aligned}\frac{\text{COST}}{(\text{Model 6.01})} = \; & h_o + h_1 \text{ (London)} \\ & + h_2 \text{ (North West)} \\ & + h_3 \text{ (Midlands)} \\ & + h_4 \text{ (South West)} \\ & + h_5 \text{ (South East)} \\ & + h_6 \text{ (South)} \\ & + h_7 \text{ (North East)} \\ & + h_8 \text{ (Provinces)} \\ & + h_9 \text{ (Wales)} \\ & + h_{10} \text{ (Scotland)} \\ & + \frac{h_{11}}{366} \text{ (No. of days from 1st Jan.1972 to date of tender acceptance)} \\ & + h_{12} \text{ (Contract Period)} \\ & + h_{13} \text{ (Offices)} \\ & + h_{14} \text{ (Workshops)} \\ & + h_{15} \text{ (Laboratories)} \\ & + h_{16} \text{ (Telephone Exchange)} \\ & + h_{17} \text{ (Hangar)} \\ & + h_{18} \text{ (Sorting Office)} \\ & + h_{19} \text{ (Post Office)} \\ & + h_{20} \text{ (Domestic Accommodation)} \\ & + h_{21} \text{ (New Boiler House Installation)} \\ & + h_{22} \text{ (New Building Installation)} \\ & + h_{23} \text{ (Sub-Contract)}\end{aligned}$$

$+ h_{24}$ (PSA/DOE Design)
$+ h_{25}$ (Consultants Design)
$+ h_{26}$ (Contractors Design)
$+ h_{27}$ (Distance from site to nearest town of 75,000 inhabitants)

In this model the variables 'distance from site to contractors office' and 'number of tenders received ÷ number of invitations' could not be included as this information would not be available to the designer at the preliminary stage of design.

The model which had the lowest standard error was as follows :-

$$\frac{\text{COST}}{\left(\begin{array}{l}\text{FUNCTION OF}\\ \text{TECHNICAL VARIABLES}\\ \text{Model 6.01}\end{array}\right)} = 0.73397$$

+ 0.19580 (London)
− 0.10265 (North West)
+ $\frac{0.17150}{366}$ (No. of days from 1.1.72 to date of tender acceptance)
+ 0.00973 (Contract period)
+ 0.28876 (Sorting Office)
+ 0.09277 (Consultant's Design)

The coefficient of variation measured as the standard error divided by the mean of the dependent variable and expressed as a percentage was 22.6%.

7. UPDATING COST INDICES

Any estimate produced by the models described in chapter 4 and ch.6 can only give an indication of what the price would have been at dates between 1st October 1971 and 31st March 1973, which was the period covered by the data. To adjust this estimate for subsequent price changes it is necessary to choose a base date, such as 31st March 1973 and calculate the estimated price for that date. The price obtained needs to be divided by the value of a suitable index at 31.3.73 and multiplied by the current value of the same index. At present the only index available universally is the N.E.D.O. (National Economic Development Office) Index for heating, ventilating and air conditioning installations, produced by P.S.A. and published by H.M.S.O..

This index is in two parts, labour and materials, the labour index being based on nationally agreed wage rates and the materials index on the wholesale prices of a 'basket of goods' comprising various materials and equipment used in heating, ventilating and air conditioning installations.

It suffers from three shortcomings : (a) labour/material ratio had to be assigned to each estimate so as to produce a single updatin g index,(b) the materials used in heating installations are not those used in heating, ventilating and air conditioning installations, (c) the index reflects wholesale prices and basic labour rates which are the basic costs of an installation and not the <u>prices</u> which have to be paid by a client.

Despite these limitations there is at present no alternative to a cost-based approach until a price-based index is available.

Consideration has been given to the development of an index based on the following procedure.

The tender price of a heating installation in the current year can be compared with the price calculated using the regression model. The ratio of the two prices gives an updating factor.

However, one sample is insufficient to place any reliability on the updating factor and a larger number of samples would be required to improve the accuracy of the index. For a number of contracts tendered in a current year the tender prices and the prices calculated in accordance with the 1972 regression model can be compared in the following manner :-

$$\text{INDEX VALUE} = \frac{\text{Sum of Tender Prices}}{\text{Sum of Calculated Prices}}$$

This gives an index which can be expressed in the following mathematical expression :-

$$I_t = \frac{\sum_{i=1}^{i=n} C_{ti}}{\sum_{i=1}^{i=n} C_{oi}} \qquad 7.1$$

Where I_t is the index value in year t, C_{ti} is the tender price of installation i in year t and C_{oi} is the price of installation i in the base year, o (zero), according to the regression model.

Although it is not possible to determine the standard error of this index precisely some approximation of its potential accuracy is given by the following formula, which gives the approximate coefficient of variation (cv) :-

$$CV(I_t) = \frac{\sigma}{\overline{T}_o}\sqrt{\frac{2}{m} + \frac{1}{n}} \qquad 7.2$$

σ is the residual standard deviation of the derived regression model, n is the number of cases upon which the regression model is based and m the number of cases in year t used to establish the index value in year t. $\overline{T}_o$ is the average base year cost for the m cases analysed in year t and thus $\sigma/\overline{T}_o$ can be regarded as the coefficient of residual variation.

This formula relies on two assumptions :-

(1) That the installations in year t do not differ appreciably in characteristics from those used to construct the regression model.

(2) That the coefficient of variation of price in year t is the same as that for the base year.

As changes in heating standards occur (1) will not hold good and in later years (2) may not hold good.

For the pre-tender model $\sigma / \bar{T}_o$ was 22%. Assuming that (1) and (2) hold good and that 25 cases are used in year t to construct the index, the coefficient of variation of the index is as follows (for n = 184).

$$CV(I_t) \doteq 22\% \sqrt{\frac{2}{25} + \frac{1}{200}}$$

$$\simeq 6.4\%$$

For m = 50 the CV is approximately 4.2%

For m = 100 the CV is approximately 2.7%

For m = 200 the CV is approximately 2.2%

This method of indexing has been estimated to take approximately 4.7 man months and require 150 cases for an index accuracy of 3%, or take 2.25 man months and require 72 cases for an index accuracy of 4%.

It should be noted that while the accuracy of this approach can be assessed, that of an arbitrarily constructed 'basket of goods' approach can not. Thus it may well be the case that the price index approach described here would be more accurate than currently used indices and would more accurately reflect the prices in which most users would be interested.

8. INTERPRETATION OF THE MODELS

(a) Pre-tender stage model

The final model, as described in paragraphs 4.09 and 4.10, comprises the variables which contributed to the model with lowest CV. Their contribution to the overall cost of an installation can be seen in Appendix 4, Page 2.

The building heat loss is a very significant variable, in fact the most significant variable. In the example shown in Appendix 4, it also contributed the greatest sum towards the total cost. The variables describing the type of heating system and the number of pumps in the building were less significant variables. The 'convector' system would increase the cost of a heating installation in a building by more than 40% and the 'pump' variable by about 5% per pump.

The sign of the 'continuous convectors', 'skirting convectors' and 'radiant panels' terms is credible as these systems are of low unit output, unlike 'unit heaters' and 'fan convectors' which are of high unit output and thereby cheaper to instal. The constants for these terms are a trifle misleading; it could be construed from the final model that the installation of a fan convector system would be very cheap. However, the data contained very few contracts with fan convectors and even on those fan convectors only provided part of the overall system. As stated in chapter 7 the model will only be reliable if used with installations of a like kind to those used in constructing the regression equation.

The boiler house terms concerned major items of plant forming part of a boiler house system and could be described as a representative sample of boiler house equipment. The cost saving from using high output boiler houses is evident from the value 0.55 attached to the terms involving boiler size, which accounts for a significant proportion of boiler house cost. This is the reason why central boiler houses are often considered as an economic alternative to a multiplicity of boiler rooms on a site containing many building s. (The unit cost of generation is also lower).

The number of boilers is also a highly significant variable and demonstrates the importance of finding the best balance between capital cost, running cost and standby capacity.

Oil tanks follow the same pattern, the unit cost being lower for the larger sizes, and the number of tanks strongly influencing the cost of the bunkering capacity.

The size of a chimney also showed economies of scale and the effect of having two chimneys of identical size was to secure a small reduction in price as signified by the value 0.9.

The terms involving boiler house circuits and pumps are somewhat correlated with the size of the boiler house capacity and proved to be of relatively low significance.

Of the 'economic' variables 'London' is significantly more expensive, which is understandable because of the premiums paid for labour and the difficulties of access to site for personnel and deliveries.

The 'north-west' and 'midlands' are cheaper than average, which may be explained by the proximity of these areas to the engineering industry where labour is more plentiful and manufactured goods are at hand.

The term involving number of days suggests a rate of inflation during 1972 of over 20% which is supported by figures published by the Department of Industry.

For a contract period of one year the contracting industry normally assumes increases in costs for $\frac{2}{3}$ of the contract period at the annual rate of inflation. This rough approximation again suggests that inflation was greater than 20%.

Sorting offices proved to be about 40% more expensive than other types of building, but the reasons are not apparent and further samples would be needed to investigate the causes.

Consultant's projects were 14% more expensive than those designed by P.S.A. As the regression model is based on quantity factors, other factors such as quality could be responsible for this increase. Consultants tend to specify equipment by name on contract drawings and in specifications. It could be that this eliminates competition among suppliers, although there is the possibility that it leads to better-quality installations because low quality goods can be excluded from consideration.

One further reason may be that the consultant's design includes a greater degree of sophistication through more controls and valves, and generous sizing of equipment to give greater margins and increased standby facilities. As consultant's fees are based on the tender price it is advantageous to design in such a way that better quality is reflected in the tender price. However, this may well be cost effective to the client in the long run because of longer life of the plant, better matching of components, lower running costs due to greater control and more flexibility for maintenance.

The choice of contractors to be included in a tender list is also important and can affect the cost in the tender. Contractors preferred by consultants may be those with higher overheads.

However, these observations are merely conjecture and only a fully detailed investigation would reveal the cause of the 14% increase.

(b) Preliminary Stage Model

The final model, described in paragraphs 6.01 and 6.02, is very similar to the pre-tender stage model in its components. Only the terms involving chimneys and oil fuel tanks change in construction, and the term involving building pumps is excluded.

Substitution of the terms involving 'storage capacity of the oil tanks' and the 'chimneys' with the 'heat output of the boilers' has not affected the accuracy of the model to any great extent but the lower statistical significance suggests that these terms are worth further study.

The observations on the other variables have been covered in 8(a).

9. SUMMARY AND CONCLUSIONS

9.01. From the analysis of the data it has been possible to establish a regression model for the PRE-TENDER stage of design which has a coefficient of variation of 22%.

There are several interesting features of the model. The size/scale effect has shown itself to be important, particularly in the case of the boiler house plant, with the indices for size falling in the range 0.25 - 0.9. This accords with an average figure of 0.6 that is suggested for plant in 'SPONS'.

The final model includes most of the boiler house variables originally suggested as being important, but excludes terms for H.W.S. Boilers, motorized valves and number of H.W.S. Calorifiers.

The explanation for H.W.S. Boilers probably lies in the situation whereby boiler houses use dual HEATING/H.W.S. Boilers and the special and separate H.W.S. Boilers noted in the data are of insignificant value, mostly being small summer boilers. The variable for boiler house pumps was highly correlated with motorized va lves and is sufficient to represent the complete hydraulic system in the boiler house up to the flow header, hence excluding the need for a separate variable to represent motorized valves. As the amount of data on H.W.S. Calorifiers was sparse the 'number' of calorifiers was deliberately discarded because of its unreliability.

For the building heat emission system the amount of heat needed by the building proved to be the most significant variable, with the type of heating system providing a noticeable trimming effect.

Interesting economic variables were the influence of London on the cost of construction and the additional cost of consultant - designed projects. The influence of the economic variables can be gauged by calculating the percentage by which they increase the total cost based on technical factors alone.

The average increase in price due to working in London is 25% ($^{0.19013}/_{0.76116}$ x 100%) but the reasons for this may not be location factor alone. There may be other reasons such as the incidence of single tenders, which would need investigation even though the London factor was highly significant.

Consultant - designed projects were 14% more expensive than P.S.A. designed projects but this variable was barely significant and the circumstances surrounding consultant - designed projects would need deeper study before any significant causes could be established.

The two inflation variables 'date of tender' and 'contract period' both proved to be highly significant and indicated a rate of inflation covering the period of over 20%.

The location factors 'north-west' and 'midlands' indicated that projects in these areas are approximately 12% cheaper than average, but these variables were barely significant and further data would be needed to confirm this result.

Sorting offices were approximately 40% more expensive than other forms of construction but the sample size was small, th is may have influenced the analysis, and further data would be needed to improve the significance and accuracy of this variable.

The most important variables were the 'heat loss of the building' and the 'heat capacity of the boilers' showing the importance of reducing the heat losses of buildings.

9.02 The PRELIMINARY STAGE model had a coefficient of variation of 22.6%, understandably less reliable than the PRE-TENDER model as the 'number of pumps in the building' technical term was not employed in the model, whilst the boiler house terms were considerably modified to suit the preliminary stage of design.

The terms involving the chimneys, oil tanks and boiler house circuits and valves suffered a deterioration in their statistical significance, but as their influence on cost is normally relatively small the derived terms used could be considered adequate.

The influence of the economic variables was still strong, as might be expected.

9.03. By the nature of heating systems most of the cost is tied up in the heating boiler system and the emitters in the building : the H.W.S. system, chimney and fuel storage system assume a lesser importance as far as cost is concerned.

This shows the importance of facilities for quickly calculating the heat losses of the building, particularly at preliminary stage of design. P.S.A. use computer facilities which can calculate heat losses readily, allowing the building services engineer to give prompt and reliable advice to his architectural colleague on the cost implications of heat losses in a particular design. I have deliberately avoided the use of cost models based primarily on heated floor area or gross floor area because they would not have taken into account the influence of standard of construction. Particularly with the recent changes in building regulations for standards of insulation, models based on floor area would have been unsuccessful because of changing construction standards.

With the models produced in this study the effect of changes in standards is minimal because they are based on functional requirements.

9.04. Having established the models for pre-tender and preliminary stages of design there are several points of interest which emerge. Perhaps most noteworthy is that the order of accuracy is comparable for both stages of design, which suggests that the preliminary stage model is the most important as it has the advantage of giving cost information to the same order of accuracy as the pre-tender model, yet the information is available at the formative stage of design when reliable cost information is most needed. However, as the accuracy of both these models depends to a great extent on the accuracy of the heat loss calculations it is understandable that the order of accuracy should be similar.

If it is accepted that the order of accuracy at pre-tender stage should be 10%, then plainly the pre-tender model with an accuracy of 22% is not suitable. However, the coefficient of variation of contracts bids has been shown to be in excess of 12% which suggests that an accuracy of 10% is not obtainable from historical data.

For pre-tender estimates there are long-standing methods of estimating, such as making preliminary enquiries to manufacturers during design, to determine current prices. These methods are more accurate in estimating the tender price because they are based on the actual prices of equipment liable to be installed rather than the 'norm' price provided by elemental costs such as Cost/m^2 or by this pre-tender model. There is an added advantage in that design and estimating through contact with manufacturers allows the designer to assess the cost benefits of recent changes in manufacture, quality, efficiency and running costs. This liaison is also the basis of value engineering because it helps to establish the best buy.

I am forced to conclude that the pre-tender model is not of geat benefit to pre-tender estimating, except that it provides a 'norm' price or 'reference' price which can be quickly calculated.

The preliminary stage model appears to have the bigger potential. By its construction it allows the Engineer to assess the cost implications of design decisions contemplated by himself and by the Architect, the principle aid perhaps being the ability to assess the impact of better building insulation on space heating installation costs. There are several other advantages of the model compared with the unit cost approach :-

1. Scale factor is taken into account.
2. It allows cost comparison of differing systems.
3. The effect of changing the number of boilers etc., can be calculated.
4. The complexity of the boiler house layout is catered for.
5. Quantifying the economic variables provides greater accuracy.

The effect of the economic variables is transient because of changing market conditions, whilst contract conditions and design standards will also change with time and cause the accuracy of the model to be eroded.

Nevertheless, the preliminary stage model has its merits and would be a useful tool for estimating at preliminary stage of design.

This study has indicated how readily regression analysis can be used to assess the factors which contribute to cost, particularly where lump sum tendering is concerned.

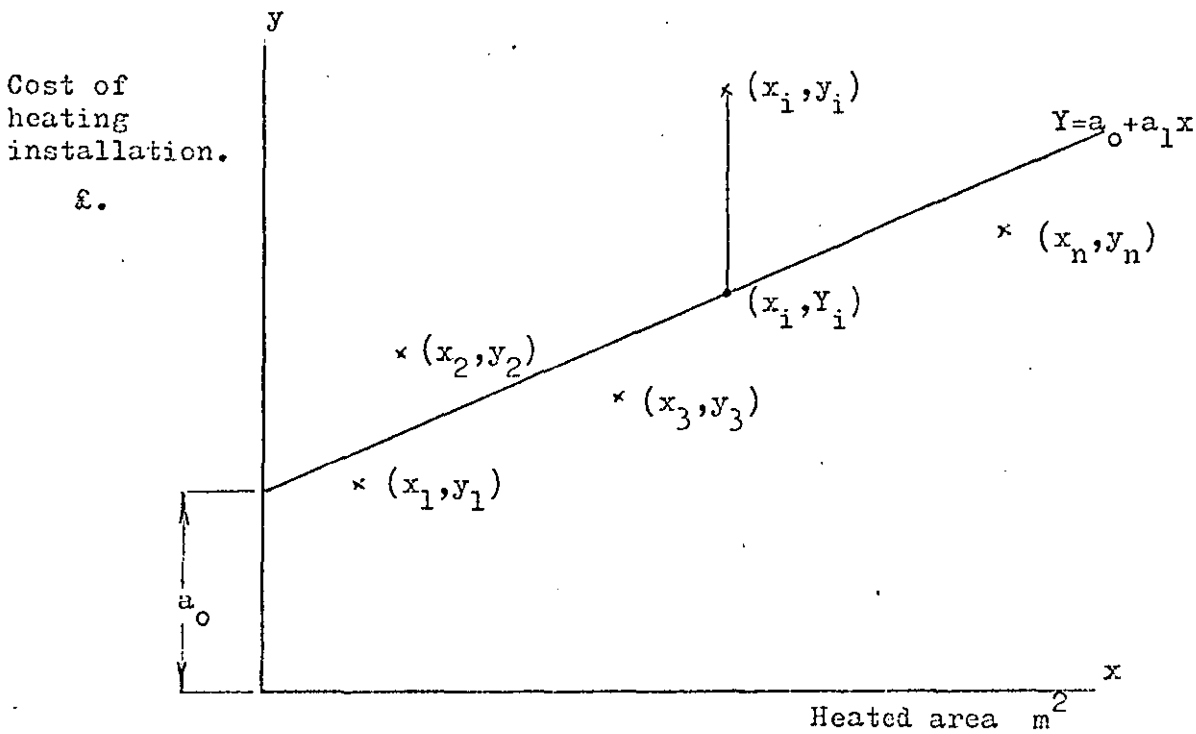
A P P E N D I X 1.

MULTIPLE LINEAR REGRESSION ANALYSIS - MATHEMATICAL PRINCIPLES

Multiple Linear Regression Analysis (MLRA) is an extension of bi-variable Linear Regression Analysis.

In the bi-variable case it could be claimed that the cost of a heating installation depended solely upon the heated area of the building into which it is fitted.

Using data on cost and heated area taken from tenders and drawings for heating installations it would be possible to plot the data on a two-dimensional graph as shown below.



The equation of the best fitting line through the data points is assumed to be :-

$Y = a_o + a_1x$, where capitals denote predicted values and small letters observed values. a_o and a_1 are the constants, (parameter estimates) to be found.

The set of data values are :-

$(x_1,y_1),(x_2,y_2),\ldots\ldots\ldots(x_i,y_i)\ldots\ldots\ldots\ldots(x_n,y_n)$.

For any point x_i the predicted value (Y_i) of y_i is $a_o + a_1x_i$

The vertical difference between the actual (y_i) and the predicted (Y_i) is $y_i - (a_o + a_1x_i)$.

The sum of squares of the n deviations is :-

SUM OF SQUARES (S.S.) = $\sum (y_i - a_o - a_1x_i)$

Minimising SS by partial differentiation with respect to a_o and a_1 and equating to zero, two equations are obtained for the parameter estimates a_o and a_1.

$$na_o + a_1\sum x = \sum y \qquad (1)$$

$$a_o\, x + a_1\sum x^2 = \sum xy \qquad (2)$$

Dividing (1) by n, equation (1) becomes

$$a_o = \frac{\sum y}{n} - a_1 \frac{\sum x}{n} = \bar{y} - a_1\bar{x} \qquad (3)$$

From (2) and (3)

$$\sum x\left(\frac{\sum y}{n} - a_1\frac{\sum x}{n}\right) + a_1\sum x^2 = \sum xy$$

$$\therefore\ a_1 = \frac{\sum xy - \dfrac{\sum x \sum y}{n}}{\sum x^2 - \left(\dfrac{\sum x^2}{n}\right)} \qquad (4)$$

$\sum x$, $\sum y$, $\sum xy$, and $\sum x^2$ can readily be found for small sets of data, but large numbers of data require a calculating machine to speed up the work.

Having found a_1 from equation (4) it is possible to find a_o from equation (3).

Hence, it is relatively easy to find the relationship between Y(cost) and x(heated area) using Linear Regression Analysis.

MLRA involving 2 or more 'independent' (x) variables uses the same principles in a multi-planar form.

For the dependence of one variable on two other variables the relationship to be fitted is of the form :-

$$Y = a_o + a_1x_1 + a_2x_2$$

The difference between the observed value y_i and the predicted value Y_i is $(y_i - a_o - a_1x_{1i} - a_2x_{2i})$

Partial differentiation with respect to a_o, a_1 and a_2 gives

$$a_1\sum(x_1 - \bar{x}_1)^2 + a_2\sum(x_1 - \bar{x}_1)(x_2 - \bar{x}_2) = \sum(x_1 - \bar{x}_1)(y - \bar{y})$$

$$a_2\sum(x_1 - \bar{x}_1)(x_2 - \bar{x}_2) + a_2\sum(x_2 - \bar{x}_2)^2 = \sum(x_2 - \bar{x}_2)(y - \bar{y})$$

If $S_1 = (x_1 - \bar{x}_1)$ and $S_2 = (x_2 - \bar{x}_2)$

Then $a_1S_{11} + a_2S_{12} = S_{y1}$

$a_1S_{21} + a_2S_{22} = s_{y2}$

In the general case

$$\begin{array}{lcl} a_1S_{11} + a_1S_{22} + \ldots\ldots\ldots\ldots + a_pS_{1p} & = & S_{y1} \\ a_1S_{21} + a_2S_{22} + \ldots\ldots\ldots\ldots + a_pS_{2p} & = & S_{y2} \\ \cdot \quad\quad \cdot \quad\quad\quad\quad\quad \cdot & & \cdot \\ \cdot \quad\quad \cdot \quad\quad\quad\quad\quad \cdot & & \cdot \\ a_1S_{p1} + a_2S_{p2} + \ldots\ldots\ldots\ldots + a_pS_{pp} & = & S_{yp} \end{array}$$

$$\text{and } a_o = \bar{y} - a_1\bar{x}_1 - a_2\bar{x}_2 \ldots\ldots\ldots -a_p\bar{x}_p$$

These equations become very time consuming to solve manually, but computer programs have been developed which complete the calculations very quickly to give the parameter estimates a_o, a_1, a_2, ... a_p for the equation

$$Y = a_o + a_1x_1 + a_2x_2 \ldots\ldots\ldots + a_px_p$$

Even better, the programs allow choice of independent variables and will reject variables which are not contributing to the accuracy of the model.

With the benefit of being able to assess simultaneously the effect of m any independent variables on the dependent variable (Y) the possibility of more accurately predicting the value of Y should be considerably improved compared with the unit cost (bi-linear) method of estimating.

In the field of piped heating installations M.L.R.A. offers the opportunity of predicting the cost of an installation if sufficient historical data can be obtained for variables which may affect the cost of a heating installation.

A P P E N D I X 2.

THE VARIABLES USED IN THE ANALYSIS

In order to carry out this study it was necessary to obtain cost and technical data concerning piped heating systems in buildings. As information was most likely to be obtainable if it referred to recently-awarded contracts the period covered by the study was set as the year 1972, with an overlap of 3 months both before and after 1972 This was partly dictated by circumstances as central records of PSA/DOE contracts was only started late in 1971, whilst the study commenced early in 1973.

From an initial sift of 12000 PSA contracts a potentially useful sample of 500 heating contracts were located. Close scrutiny of the contract documents pruned this batch down to 250 contracts of a type which related to the study and for which both cost and technical data might be obtainable. From this total, 200 contracts that were suitable for analysis and for which the Design Engineer could provide drawings constituted the basic material from which data could be obtained.

The criterion for proceeding with data extraction on any contract was that it should be possible to obtain from the tender summary a price for a defined type of heating installation. In the case of 50 contracts it was impossible to segregate the cost of the heating installation from the overall tender sum or to establish a defined amount of new work corresponding to the following 8 types of piped heating system : radiators, overhead radiant panels, unit heaters, free-standing or ceiling mounted fan convectors, free-standing natural convectors, wall-hung continuous convectors, skirting level continuous convectors, underfloor or overhead pipe coils.

V1. <u>Contract Number</u>

A number between 1 and 600 used to reference each contract, and used as a cross-reference on computer printouts. It does not form one of the series of variables used in the Regression Analysis of the data.

V2. <u>Accepted Contract Sum</u>

The contract price agreed between P.S.A. and the Successful Contractor for the whole of the contract, which often included systems such as compressed air, town gas or hot water installations as well as the cost of the heating installation.

V3. <u>Number of Heated Rooms</u>

The number of enclosures in the building containing a heating device. An enclosure can be a room, corridor, staircase or lobby.

V4. <u>Cost of the heating installation in the Building</u>

For the building (as distinct from the Boiler House/Calorifier Room/Pump Room) the cost of the emitters, pipework, pumps and control valves expressed as a sub-total of the accepted contract sum. This variable was not always available.

V5. <u>Number of Storeys of Heated Rooms</u>

Each building has a principal floor (usually the basement, ground or 1st floor) which has the typical area of the other floors above and below it, (although it can be very much bigger). The number of storeys of heated rooms is the ratio TOTAL FLOOR AREA divided by PRINCIPAL FLOOR AREA, to the nearest whole number.

V6. <u>Cost of Heating Boiler Installation</u>

Within the accepted contract sum the separate cost of the heating boiler system. This variable could not always be determined.

V7. <u>Number of Tenders Invited</u>

The number of Contractors invited to submit a bid.

V8. <u>Total Capacity of Heating Boilers</u>

The aggregate rated output of the heating boilers, measured in kilowatts

V9. Number of Heating Boilers

V10. Building Fabric Heat Losses

This figure was obtained by summation of the heat lost through the walls, roof and floor of the building.

For each room with an exterior facing surface the heat lost through surface was calculated according to the formula :-

Heat Lost (kW) $= \frac{U.A.dt}{1000}$ where U is the thermal transmittance coefficient in watts/m^2/°C
A is the surface area in square metres
dt is the temperature difference between the room and the outs de air in °C

V11 Percentage of Inaccessible Pipework in the Building

By definition this is :

$$\frac{\text{Length of Inaccessible Pipe in the Building}}{\text{Total Length of Pipe in the Building}}$$

(Inaccessible pipe is defined as pipework in enclosed ducts or above 2 metres from the floor and requiring trestles or scaffolding for access).

V12. Total Capacity of Heating Calorifiers

The aggregate rated output of the heating calorifiers, measured in kilowatts.

V13. Number of Heating Calorifiers

V14. Room Volume x Room Temperature Difference (V.dt)

This figure was obtained by the summation of the V.dt values for all the heated rooms in the building. (V is the volume of the heated rooms in m^3 and dt is the temperature difference between the room and the outside air in °C.

V15. Boiler Flow Temperature

The water flow temperature from the heating boiler(s) in °C.

V16. Total Floor Area of Heated Rooms

Measured in m^2.

V17. Boiler Return Temperature

The temperature of the water returning to the heating boiler (s) measured in °C.

V18. Volume of Heated Rooms

Measured in m^3.

V19. Number of days from 1.1.72 until the date of Contract between P.S.A. and the Heating Contractor

V20. Design Building Heat Losses

The figure was obtained from the designer, who inserted the number on a standard reply sheet.

V21. Contract Period

The Contract period, measured in months. For a contract made directly between P.S.A. and the specialist heating contractor it is the actual contract period. When the specialist heating contractor is a nominated sub-contractor to a building Contractor it is the contract period for the contract made directly between P.S.A.. and the building contractor.

V22. Total Principal Floor Area

The principal floor is that which has the typical area of the floors above and below it. It is usually the ground floor, b ut can be the basement or even the 1st floor if the ground floor is a car park beneath the building structure. The total principal floor area includes all the enclosed areas on the principal floor and is measured in m^2.

V23. Number of Chimneys

The number of self-supporting chimneys to P.S.A. Specification M.& E. No.7.

In the case of multi-flue chimneys the number of chimneys is not altered by the number of flues in one chimney.

V24. Chimney Diameter

The chimney diameter is taken as the diameter of the flue, in millimetres.

For a multiflue chimney the dimension taken is the sum of the flue and casing diameters and is called the effective diameter.

V25. Chimney Height

The height is measured from the base of the chimney to the apex, in metres.

V26. External Wall and Window Area

The wall and window area of the building envelope, measured in m^2

V.27 Number of Hot Water Service Calorifiers

V28. Capacity of Hot Water Service Calorifiers

The aggregate capacity, in litres,of the hot water service calorifiers.

V29. Number of Oil Tanks

The number of boiler oil fuel bulk storage tanks.

V30. Capacity of Oil Tanks

The aggregate capacity, in litres, of the boiler oil fuel bulk storage tanks.

V31. Percentage of Heat by Convectors

The percentage of the building heat requirements supplied through convectors. (Fan Convectors, Natural Convectors, wall mounted or skirting continuous convectors).

V.32. Adjacent Wall Area

The area in m^2, of the building which abuts an existing building.

V33. Number of Air Changes

The air change rate was given by Design Engineers, but varied from room to room. This variable was used as an indicator that information was available and had been obtained using code 0.07.

V34. Total Floor Area

The total floor area of the enclosed areas of the building in m^2.

V35. Number of Boiler House Circuits

The heating boiler has a flow circuit which is usually branched within the boiler house to serve various circuits in the building. If the boiler is a dual heating/H.W.S. boiler it also has a branch to the H.W.S. Calorifier. The number of circuits is counted as the sum of branch circuits leaving the boiler house plus one for a H.W.S. Calorifier branch.
(If the H.W.S. calorifier is served by a H.W.S. boiler the calorifier branch is not counted in the total).

V36. Cost of Boiler House and Building Heating Systems

The over-riding principle in the formulation of the cost variable is that the cost must be reflected in the variables of the model. The building element of the heating installation must be a complete and working installation with one or more of the following types of system :- radiators, continuous wall-hung convectors, unit heaters, radiant panels, fan convectors, natural convectors, pipe coils or continuous skirting convectors. Systems such as overhead radiant hot air tube, radiant ceilings, free-standing gas or oil fired air heaters, plenum systems and air-conditioned systems are excluded. (In the case of small plenum systems within a building containing (say) a major radiator scheme it is allowable to treat the heater battery of the plenum system as a unit heater and exclude the cost of the ductwork and air handling equipment from the total cost of the contract). Variables have been included in the model to reflect the heat emitters, pipework, valves and controls which constitute the whole installation within the building.

It is a different situation within the boiler house/calorifier room. A boiler house contains a permutation of the following equipment :-

Heating boilers, hot water service boilers, heating calorifiers, hot water service calorifiers, boiler flues, chimneys, oil tanks, pumps, motorized valves, pipework, controls and control panel, feed expansion tank, gas pipework and equipment and fittings, oil supply pipework and safety devices, pressurisation sets, etc.. In principle the presence or absence of the heating boilers, hot water service boilers, heating calorifiers, hot water service calorifiers, chimneys, oil tanks, pumps and motorized valves, determines whether the ancillary equipment would be present e.g. if a heating boiler is present it ensures that a flue, feed and expansion tank, gas or oil supply, a selection of controls and some pipework is also present. Thus the presence of a heating boiler implies the presence of other equipment and'the heating boiler system' to give it a name, can be represented by the size of the heating boiler. It is therefore possible to have any permutation of boiler house equipment and to represent the cost by the principal components, e.g. a gas-fired boiler of 500 kW with a balanced flue, serving a H.W.S. calorifier of 1000 litres, and having two heating circuits controlled by two 3-way motorised valves, duplicate pumps on each circuit, and a primary H.W.S. pump with one controlling 3-way motorised valve, can be represented by the following values :-

Capacity of heating boilers	- 500
Number of heating boilers	- 1
Capacity of H.W.S. Calorifier	1000
Number of circuits	- 2 + 1 (for H.W.S. circuit)
Number of pumps	- 4 + 1 (for H.W.S. circuit)
Number of motorized valves	- 2 + 1 (for H.W.S. circuit)

The foregoing assumes a new installation in the boiler house or the building. This is only true in about half of the contracts analysed, and it was necessary to adjust the contract sum given by the successful tenderer in order to take account of work in existing or extension buildings and boiler houses.

As a principle it is necessary to adjust the price of an installation so that it can be represented by the variables in the model as if it were a new installation.

For the building the problems usually concern an extension to an existing building e.g. if an extension of 10000 m^2 heated floor area is added to an existing building, where the heat losses for the extension are 300 kW and £350. worth of work is carried out in the existing building, the extension can be considered as a building of 10000 m^2 heated floor area, heat losses 300 kW with the tender price abated by £350. (The calculation of £350. would have been carried out by pricing the work in the existing building from the schedule of rates provided with the contract).

For the boiler house it is often the case that the equipment becomes redundant due to the addition of a large extension to the existing building, and it is refurbished with boilers sized to suit the new scheme (which includes the existing building). The new pipework layout is often arranged to connect to existing pipes serving the old building and this fact is reconciled in the variable for'circuits in the boiler house' e.g. if there were three existing flow pipes connecting to the old building and three new pipes are arranged to connect them to the new system, the variable for 'circuits' is increased by three.

At times the amount of work in the building or the boiler house which is 'work on the existing installation' is so great that reliable pricing adjustment is impossible. For these contracts it is sometimes possible to use the itemised part-price for specific equipment if it is available on the summary of tender, otherwise the contract is not usable. e.g. in a boiler house with existing gas boilers where a new chimney and new oil tank system is installed it is allowable to treat the boiler house as a chimney and oil tank installation, if the itemised prices of these items are available. However, it is not allowable to treat the replacement of a boiler as a priceable item if the ancillary equipment has not been renewed as well, since the variables for the boiler represent the ancillary equipment such as controls and control panel which have not been renewed.

All cost information is available from P.S.A. document 'Schedule 4 - Summary of Tender', and amending correspondence between P.S.A. and the successful tenderer up to the date of tender acceptance.

Schedule 4 is laid out in a standard format which allows the tenderer to summarise his price under several heading, namely :-

1.1. Boiler plant
1.2. Oil storage tanks
1.3. Plant in calorifier chamber
1.4. Services in buildings
- (1) Heating
- (2) Domestic hot water service
- (3) Steam and condensate
- (4) Cold water service
- (5) Town gas
- (6) Other services

1.5 Site distribution :
- (1) Heating mains
- (2) Domestic hot water service mains
- (3) Steam and condensate mains
- (4) Town gas mains
- (5) Other services

2.1. Cost of pre-commissioning cleaning
2.2. Cost of inspection and tests
2.3. Cost of efficiency tests on flue gas losses
2.4. Cost of maintenance instructions
2.5. Cost of "As installed" drawings

In the case of most contracts it is readily clear that the work shown on the drawings has been properly priced and included under the correct headings. However, some contracts include work which falls outside the main headings on Schedule 4 and it is not clear under which heading it has been included. This implies that the itemised prices are not altogether trustworthy, but a reasonable guarantee of accuracy can be expected if items 1.1, 1.2, 1.3, 1.4(1), 2.1, 2.2, 2.3, 2.4, and 2.5 are summed to get Total Cost. Care must be taken to include for gas and cold water supplied to the boiler which may have been included under 1.4(4) and 1.4(5).

For sub-contracts 1/39th of the Total Cost has been added to allow for Main Contractor's discount for prompt payment.

V37. Number of Hot Water Service Boilers

V38. Building Air Infiltration Heat Loss

Each room of a building has a certain amount of air circulation whereby cold air from outside comes into the building either deliberately by fans designed to bring in fresh air, or by natural ventilation through windows and doors.

The heat required to warm that air to room temperature can be calculated by the equation :-

$$\text{Heat} = \frac{V.SH.AC.dt}{1000}$$

where V is the room volume in metres^3
SH is the specific heat of air in watts/m^3/$^{\circ}$C
dt is the difference between inside and outside temperature in $^{\circ}$C
AC is the design air change rate for the room.

For each volume of the building the heat loss can be calculated and summated to give the total heat loss by infiltration.

V39. Capacity of Hot Water Service Boilers

The aggregate output, in kilowatts of the H.W.S. Boilers.

V40. Cost of Boiler House Systems

The itemised price for all the boiler house plant. In some cases this could be segregated from the accepted contract price.

V41. Distance from Site to Contractors Office.

This is the distance in miles, of the site to the Contractor's office submitting the tender.

V42. Distance from Site to the nearest town of 75,000 inhabitants (In miles)

V43. Number of Boiler House Pumps

Within the heating system in the boiler house there are circulating pumps on the flow circuits.

For a dual heating/HWS boiler there is often a pump on the flow pipe to the H.W.S. Calorifier.

This variable is the sum of all these pumps.

V44. Number of Boiler House 2 or 3-way motorised valves

Within the heating system in the boiler house there are 2 or 3-way motorized control valves on the flow and return circuits and on the boiler return pipes.

For a dual heating/H.W.S. boiler there is often a 2 or 3-way valve on the flow pipe to the H.W.S. calorifier.

This variable is the sum of all these valves.

V45. Dummy for H.W.S. Boiler

If a H.W.S. boiler is present the variable takes the value 1, otherwise the variable is 0.

V46. Cost of H.W.S. Boiler

The itemised price for the H.W.S. boiler system, if available.

V47. Dummy for H.W.S. Calorifier

If a H.W.S. calorifier is present the variable takes the value 1, otherwise it is zero.

V48. Cost of H.W.S. Calorifier

The itemised price for the H.W.S. Calorifier system, if available.

V49. Dummy for Heating Calorifier

If a heating calorifier is present the variable takes the value 1, otherwise it is zero.

V50. Cost of Heating Calorifier

The itemised price for the heating calorifier system, if available.

V51. Dummy for Oil Tanks

If an oil tank is present the variable takes the value 1, otherwise it is zero.

V52. Cost of Oil Tanks

The itemised price for the boiler oil fuel bulk storage tank system, if available.

V53. Dummy for Chimneys

If a chimney is present the variable takes the value 1, otherwise it is zero.

V54. Cost of Chimneys

The itemised price for the chimneys, if available.

V55. Dummy for heating Boilers

If a heating boiler is present the variable takes the value 1, otherwise it is zero.

V56. Dummy for Boiler House Circuits

If there is at least one circuit the variable takes the value 1, otherwise it is zero.

V57. Dummy for Boiler House Pumps

If a boiler house pump is present the variable takes the value 1, otherwise it is zero.

V58. Dummy for Boiler House 2/3-way Valves

If a boiler house 2 or 3-way valve is present the variable takes the value 1, otherwise it is zero.

V59. Total Building Heat Losses

In this exercise it has been obtained in one of three ways :-

(a) Directly from the design engineer (Variable 20).

(b) As the sum of variables 10 & 38.

(c) Taken from the notes on the drawings.

In most cases the figure given by the Engineer or shown on the drawings has been used, but this has been checked against the calculated sum of variables 10 & 38.

For installations in existing buildings or extensions the calculated figure has normally been used.

V60. Heat Supplied to the Building

This has been assessed as follows :-

1. As variable 8 if a heating boiler is present.
2. As variable 12 if a heating calorifier is used instead of a boiler.
3. As variable 59 if the supply is from a district heating main.

NOTE : All dummies take the value 1 if the title is applicable, and zero if not applicable.

REGION OF SITE (61 - 71)

V61. London
V62. North West
V63. Midlands
V64. South West
V65. South East
V66. South
V67. East
V68. North East
V69. Provinces (i.e. Not London)
V70. Wales
V71. Scotland

TYPE OF BUILDING (72 - 79)

V72. Offices
V73. Workshops
V74. Laboratories
V75. Telephone Exchange
V76. Hangar
V77. Post Office Sorting Office
V78. Post Office
V79. Domestic Accommodation e.g. Barracks, Hostels.

CONTRACTUAL & DESIGN FACTORS

V80. For new boiler house

V81. For new building

V82. For sub-contract

V83. For principal contract (known otherwise as main contract or direct contract).

V84. Number of tenders received

V85. For P.S.A. designed project

V86. For Consulting Engineer - designed project

V87. For design by installation contractor.

EMITTER FACTORS

V88. Total number of radiators

V89. Heat output of radiators, in kilowatts

V90. Total casing length of wall-hung continuous convectors, in metres

V91. Heat output of wall-hung continuous convectors, in kilowatts

V92. Total length of overhead radiant panels, in metres

V93. Heat output of overhead radiant panels, in kilowatts

V94. Total number of unit heaters

V95. Heat output of unit heaters, in kilowatts.

V96. Total number of fan convectors

V97. Heat output of fan convectors, in kilowatts

V98. Total number of natural convectors

V99. Heat output of natural convectors, in kilowatts

V100. Total length of hot-air radiant tube, in metres

V101. Heat output of hot-air radiant tube, in kilowatts

V102. Total length of pipe coils, in metres

V103. Heat output of pipe coils, in kilowatts

V104. Total number of free-standing air heaters

V105. Heat output of free-standing air heaters, in kilowatts

V106. Total casing length of skirting continuous convectors, in metres.

V107. Heat output of skirting continuous convectors, in kilowatts

V108. Complexity Factor

The complexity factor is a semi-subjective valuation for several factors which contribute to the complexity of the heating installation within the building. Seven factors were given a weighting up to 10.

For each contract the factors were assessed as follows :-

(a) Each type was given a weighting of 1 (One) so that if a building contained radiators and unit heaters the contribution to complexity factor was 2.

(b) Changes in direction of the pipework

This factor was given a value up to 10 depending on the assessed number of changes in direction per 100 metres in the pipework.

(c) Congestion of other services

Each piped service such as H.W.S., compressed air, town gas etc., which followed the route of the heating system was given a weighting of 1 (one).

(d) High Level pipework

A contract with 95% - 100% of pipework at high level was given a weighting of 5, 70 - 95% was given 4, 50 - 70% was given 3, 30 - 50% was given 2, 10 - 30% was given 1, 0 - 10% was given 0.

(e) Trade sequencing

A weighting of up to 10 was given for the amount of co-ordinating required with the builders installation. A contract with all pipework and emitters within a continuous convector heating installation was given a value of 10, with pro rata ratings for contracts with a percentage of heat by continuous convectors. A contract with all pipework enclosed in false ceilings or partitions was given a value of 8, with pro rata ratings for contracts with semi-enclosed pipework.

(f) Number of control valves

A weighting of up to 5 was given depending on the density of control valves such as regulating valves, stop valves etc.

(g) Lagged pipework

A weighting of up to 10 was given depending on the percentage of lagged pipework

V109. <u>Number of Pumps in the Building</u>

Some systems have pumps situated in the building and in the boiler house. This variable is the total number of pumps installed in the building.

V110. <u>Number of 2 or 3-way motorized valves in the building</u>

Some systems have 2 or 3-way motorised valves within the building and the boiler house. This variable is the total number of 2 or 3-way motorised valves in the building only.

V111. <u>Total length of pipe in the Building</u>

Measured in metres.

APPENDIX 3.

COMPUTER WORK

3.01 Loughborough Computer Facilities

The University of Technology at Loughborough have an I.C.L. 1904A computer which is operated by the full-time staff of the Computer Centre.

Core storage up to 84k words is available for normal use, with store facilities on magnetic drum, exchangeable disc or magnetic tape.

Other equipment available to the computer centre includes card readers, paper tape reader, line printer, card punches, paper tape punch, graph plotter, multiplexors for remote terminals, verifiers, card interpreter, card producer and a card sorter.

For this particular study the input to the computer comprised punch cards, usually combined with data and operating programs held on disc or magnetic tape. The output was always in the form of standard computer printout from the line printer and usually written to magnetic tape for storage.

Throughout the work FORTRAN IV was the language used in programming.

3.02 The Multiple Linear Regression Program, NO2R

A choice existed between an I.C.L. program (called XDS 3 by code name) and a program developed by the University of California, Los Angeles (U.C.L.A.)(called NO2R by code name).

On the advice of Mr. B. Negus of the Loughborough University Computer Centre the U.C.L.A. program was adopted for this research. It is one of a series of programs which was originally devised for use on biomedical problems and is titled STEPWISE REGRESSION, BMDO2R. The reference to stepwise means that the program will add variables to the regression model in a step-by-step fashion according to a set of predetermined rules; at each step one variable is added to the regression equation, the one added being that which makes the greatest reduction in the error sum of squares. (Equivalently it is the variable with the highest F-value. The F-value of a variable is the square of the t-statistic, which in turn is the ratio of the regression coefficient and the standard error of the regression coefficient. To be significant at the 95% confidence level the value of F should be greater than 4, and to be highly significant at the 99% confidence level F should be greater than 7). Variables are automatically removed from the regression when their F-value becomes too low (if they are variables which have not been 'forced' to stay in the regression). Regression equations with or without a regression intercept may be selected.

The output from the program gives statistical information on the data analysed by the program as well as the results of the regression analysis.

It includes :

(1) At each step:

(a) The correlation coefficient of the model.

(b) The standard error of the model.

(c) An analysis of variance table.

(d) For variables in the equation :

1. Regression coefficient
2. Standard error.
3. F-value.

(e) For variance not in the equation.

1. Tolerance.
2. Partial Correlation Coefficient.
3. F-value.

(2) <u>Optional Output Prior to Performing Regression :</u>

(f) Means and standard deviations of each variable.
(g) Covariance matrix.
(h) Correlation matrix.

(3) <u>Optional Output after Performing Regression :</u>

(i) List of residuals
(j) Residuals plotted against input variables.
(k) Summary table.

The capabilities and limitations of the program are as follows :-

(1) Within the same computer run an unlimited number of regression trials can be carried out using the same set of basic data. For instance, in one series of trials one might wish to study the effect of $y = x^{0.1}$, $y = x^{0.2}$, $y = x^{0.3}$ etc.. There exists a facility called TRANSGENERATION whereby a variable, say x, can be TRANSGENERATED into $x^{0.1}$, $x^{0.2}$, $x^{0.3}$ etc. in each trial in turn.

(2) Sample size $\leqslant$ 9999.

(3) Number of original variables $\leqslant$ 80.

(4) The number of variables added by transgeneration $\leqslant$ 78.

(5) Within each regression trial there are various features about which an option can be made :

(a) The choice of dependent variable
(b) The F-value for including or deleting a variable
(c) The tolerance level for including a variable
(d) The number of plots of residuals against input variables
(e) The options of 2(f) - (h) and 3 (i) - (k) above

All of these choices can be exercised in combinations and each combination can be tried separately within each regression trial.

(6) The number of plots of residuals against input variables $\leqslant$ 30.

3.03 The Data Handling Program : PRE-NIMBUS

3.03.1. Previous experience by Mr. P.R. Gould on the use of Multiple Linear Regression Analysis using computers had shown that the method of presenting data to the computer was an important feature of the analysis technique. A method was needed which allowed an arbitrary choice of data combined with economy of effort so as to allow the maximum use of time. Punch cards were liable to become damaged or lost and data sorting was time-consuming, so as part of the current research a computer program was devised which would allow complete freedom to choose a data matrix of any given size and to pass these data to the NO2R statistical program for analysis.

It was envisaged that a maximum of 200 contracts could be obtained for analysis and that 50 basic variables could be extracted from the contract particulars for each of those 200 contracts. (In the event 111 basic variables were obtained and the method of dealing with this problem is discussed in 3.04.

A program was written by Mr. R.C. McCaffer of the University of Technology, Loughborough with advice from Mr. B. Negus of the Computer Centre, which would make it possible to record all the data on magnetic tape in matrix format, and would allow taped data to be used as an input document to the statistical program (NO2R).

Several very important features were incorporated into this program, (called the DATA HANDLING PROGRAM and code named PRE-NIMBUS) and they are described below :-

(a) Data Validation

The variables have values which fall between certain bounds and it was arranged that these bounds could be set for each variable. Each data value could be tested to determine whether or not it fell within the limits. The object of carrying out this test was to detect human errors where data on punched cards had been mispunched or where data had been incorrectly transferred to new data tapes during analysis and computer work.

(b) Contract Selection

It was a necessary requirement of the data handling program that contracts could be selected for a regression trial. This was essential because some contract data were temporarily incomplete or were not suited to a particular situation. For instance, if a regression trial on boiler houses was being considered and a particular contract did not include for boiler house work that case was of no use to the analysis and needed to be deleted from the regression trial.

(c) Data Editing

One vital feature of the program was that it should be possible to change a data value if it was in error and needed to be altered.

(d) Transgeneration of Variables

Whilst it was possible to carry out transgeneration of variables within the NO2R program, the scope allowed by this program was limited and the method of carrying out the transgenerations was relatively cumbersome.

This part of the PRE-NIMBUS program allowed fortran statements to be used in order to generate new functions from existing variables e.g.,

`Y(1) = (X(1) + X(2)) * X(3)`	($Y_1 = (X_1 + X_2)X_3$)
`Y(2) = (X(1) + X(2) + X(3))`	($Y_2 = (X_1 + X_2 + X_3)$)
`Y(3) = (X(1) + X(3)) / X(2)`	($Y_3 = (X_1 + X_3)/ X_2$)

Combined with the NO2R transgeneration facility it was possible to create complex derived variables from the basic variables.

(e) Program Error Detection

The pre-nimbus program included error traps to detect user errors and all of these were initially tested by creating deliberate mistakes on data cards in order to provoke the appropriate error trap and ensuing error message.

3.03.2. One of the principal demands of the data handling program was that it should enable data to be stored on magnetic tape in such a form that it was acceptable to the NO2R statistical program as a data input document.

In order that the data was in the correct form for a regression trial the following sequence of events occured :-

1. COMPUTER READS CURRENT DATA MATRIX M1 FROM MAGNETIC TAPE 1.
2. ADDS ADDITIONAL CASES TO MATRIX M1 TO FORM MATRIX M2.
3. ADDS ADDITIONAL VARIABLES TO MATRIX M2 TO FORM MATRIX M3.
4. EDITS THE MATRIX M3 TO FORM MATRIX M4.
5. VALIDATES MATRIX M4.
6. WRITES MATRIX M4 TO MAGNETIC TAPE 2.

Having created a new data matrix to form the up-to-date data record a sequential list of actions is performed by the computer.

1. COMPUTER READS DATA MATRIX M4 FROM MAGNETIC TAPE 2.
2. SELECTED CASES ARE DELETED FROM MATRIX M4 TO FORM MATRIX M5.
3. SELECTED TRANSGENERATIONS ARE PERFORMED ON MATRIX M5 TO FORM MATRIX M6.
4. WRITES MATRIX M6 TO MAGNETIC TAPE 3.

Magnetic tape 3 is used as the input document to the statistical program NO2R.

The system control cards which steer the computer through the sequence of job operations were arranged such that the PRE-NIMBUS program and the NO2R program could operate sequentially within the same computer run. This allowed re-creation of data tapes and regression analysis within the same computer run, and in consequence with the minimum time lapse.

In the early stages the pre-nimbus program was run from punched cards. When it had been thoroughly tested and all improvements and amendments completed arrangements were made to dump the program onto disc storage. The job control cards were altered to 'call' the PRE-NIMBUS program into use during the computer run.

3.04 Storing the Data on Magnetic Tape

The Loughborough Computer facilities allowed a maximum of sixty variables and two hundred contracts to be used in one matrix.

This meant that the 111 variables extracted from the contract documents could not be stored together on one magnetic tape and in consequence could not all be used in one regression trial.

This was not absolutely necessary as some of the variables were inappropriate to certain trials. Separate regressions on the boiler house and building variables could be accomplished readily. This established the significant variables and reduced the total number of variables needed for the total model.

To reduce the data handling and storage problem magnetic tape storage of the data was arranged as follows :-

1. The first 60 variables (V1-V60) being principally technical variables, were read onto a tape called BASIC.

2. Having carried out regression trials for both the Boiler House and Building Elements it became plain which variables were statistically significant and should be combined with the economic variables.

To do this the boiler house variables were written to a tape called BOILER and the economic variables added.

For the building variables the significant ones were written to a tape called BUILDING and the economic variables added, together with additional technical variables dealing with complexity.

3. Having carried out further regression trials with both technical and economic variables using BOILER and BUILDING tapes, it was necessary to take the significant variables from both tapes and write the data to a fourth tape called COMBINED.

4. As the computer was already using its maximum core storage when reading from one tape of matrix size 60 x 200 and writing to another of 60 x 200 it was necesarry to write all significant boiler variables to a tape called X, which only had a matrix size of 10 x 200. All building technical variables, and the economic variables, were written to a tape called Y of matrix size 50 x 200.

The Computer was then used to read X and Y together and to write the resulting matrix to the tape called COMBINED.

In this way, all the significant variables which had been previously located on two tapes were re-located onto one tape suitable for use as an input to the PRE-NIMBUS and hence the NO2R program.

3.05 The Statistical Program E02ABF

This program calculates a weighted least-squares polynomial approximation to a set of data points by Forsyth's method using orthogonal polynomials, and was arranged by the Nottingham Algorithms Group. The Loughborough Computer Centre have incorporated it into their standard library of computer programs.

For the polynomial $y = a_o + a_1x + a_2x^2 + a_3x^3 \ldots a_nx^n$ the program computes the coefficients of the polynomial $(a_o \rightarrow a_n)$ by minimising the sum of squares of the expression. The choice of n lies with the user and each data point can be weighted if desired. The output gives the coefficients of the polynomial and a measure of the goodness of fit.

This program was seen as a means of determining how well cost was related to the variables in a polynomial expression.

The expression which I wished to consider was as follows :-

$$\frac{COST}{W} = \frac{a_o}{W^3} + \frac{a_1}{W^2} + \frac{a_2}{W} + a_3 + a_4W + a_5W^2 + a_6W^3$$

where W is the building heat losses and COST is the cost of the heating installation in the building. n is 6.

By rearrangement :-

$$COST.W^2 = a_o + a_1W + a_2W^2 + a_3W^3 + a_4W^4 + a_5W^5 + a_6W^6$$

$$\text{i.e.} \quad y = a_o + a_1x + a_2x^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots a_nx^n$$

which is the polynomial expression that E02ABF can solve.

A program was written which caused the computer to read the data from the up-to-date magnetic tape and to use the data in determining the best polynomial and its goodness of fit by use of the E02ABF statistical program.

However, the results obtained from this program were not worth pursuing because there were considerable scale effects caused by the power relationships.

A P P E N D I X 4.

THE PRE-TENDER STAGE MODEL EXPRESSED IN TERMS OF THE VARIABLES DESCRIBED IN APPENDIX 2.

(V36) (TOTAL COST OF BUILDING AND BOILER HOUSE HEATING INSTALLATION) =

TECHNICAL VARIABLES

$$
\begin{aligned}
(V36) = \Big(& + 57.60917(V59)^{0.85} \\
& + 24.30901(V59)^{0.85}(V91/TOTAL) \\
& + 106.94150(V59)^{0.85}(V107/TOTAL) \\
& + 32.81960(V59)^{0.85}(V93/\ TOTAL) \\
& - 28.39179(V59)^{0.85}(V95/TOTAL) \\
& - 53.94303(V59)^{0.85}(V97/TOTAL) \\
& + 3.88239(V59)^{0.85}(V109) \\
& + 171.99084(V9)^{0.2}(V8)^{0.55} \\
& + 229.84913(V13)^{0.2}(V12)^{0.55} \\
& + 404.87226(V28)^{0.25} \\
& + 5.87032(V29)^{0.5}(V30)^{0.5} \\
& + 0.33238(V23)^{0.9}(V24)^{0.9}(V25)^{0.9} \\
& + 6.19710(V35)\left[(V8)^{0.5} \text{or} (V12)^{0.55} \text{or} (V59)^{0.55}\right] \\
& + 11.62477(V43)\left[(V8)^{0.5} \text{or} (V12)^{0.55} \text{or} (V59)^{0.55}\right] \Big)
\end{aligned}
$$

x

ECONOMIC VARIABLES

$$
\begin{aligned}
\Big(& \quad 0.76116 \\
& + 0.19013(V61) \\
& - 0.09787(V62) \\
& - 0.09337(V63) \\
& + 0.16413(V19)/366 \\
& + 0.00871(V21) \\
& + 0.29583(V77) \\
& + 0.10646(V86) \Big)
\end{aligned}
$$

(TOTAL = V89+V91+V93+V95+V97+V99+V103+V107+0.00001)

The number 0.00001 was used to prevent the indeterminate figure 0/0 from occuring, which would have prevented the computer from operating on the data.

This model was used to calculate the expected cost of case 137, Crown Offices, Cardiff for which the actual cost of the boiler house and building heating in stallation was £109 529.

	£.
$57.60917(2200)^{0.85}$	39 949.7
$+ 24.30901(2200)^{0.85}(1914.49/1949.21001)$	16 557.1
$+ 106.94150(2200)^{0.85}(0/1949.21001)$	0.0
$+ 32.81960(2200)^{0.85}(0/1949.21001)$	0.0
$- 28.39179(2200)^{0.85}(0/1949.21001)$	0.0
$- 53.94303(2200)^{0.85}(0/1949.21001)$	0.0
$+ 3.88239(2200)^{0.85}(0)$	0.0
$+ 171.99084(2)^{0.2}(3810)^{0.55}$	18 416.5
$+ 229.84913(0)^{0.2}(0)^{0.55}$	0.0
$+ 404.87226(4390)^{0.25}$	3 295.4
$+ 5.87032(0)^{0.5}(0)^{0.5}$	0.0
$+ 0.33238(0)^{0.9}(0)^{0.9}(0)^{0.9}$	0.0
$+ 6.19710(6)(3810^{0.5})$	2 294.9
$+ 11.62477(10)(3810^{0.5})$	7 174.7
	87 688.3
x	
0.76116	0.76116
$+ 0.19013(0)$	0.0
$- 0.09787(0)$	0.0
$- 0.09337(0)$	0.0
$+ 0.16413(62)/366$	0.02780
$+ 0.00871(32)$	0.27872
$+ 0.29583(0)$	0.0
$+ 0.10646(1)$	0.10646
	1.17414

TOTAL COST = £87 688.3 x 1.17414 = £102 958.2

A P P E N D I X 5.

THE PRELIMINARY STAGE MODEL EXPRESSED IN TERMS OF THE VARIABLES DESCRIBED IN APPENDIX 2.

(V36) (TOTAL COST OF BUILDING AND BOILER HOUSE HEATING INSTALLATION) =

TECHNICAL VARIABLES

$$
\begin{aligned}
(V36) = \Big(& \; 59.95960(V59)^{0.85} \\
& + 25.00131(V59)^{0.85}(V91/TOTAL) \\
& + 101.84609(V59)^{0.85}(V107/TOTAL) \\
& + 33.26266(V59)^{0.85}(V93/TOTAL) \\
& - 28.69273(V59)^{0.85}(V95/TOTAL) \\
& - 53.41300(V59)^{0.85}(V97/TOTAL) \\
& + 172.66727(V9)^{0.2}(V8)^{0.55} \\
& + 231.17664(V13)^{0.2}(V12)^{0.55} \\
& + 401.92386(V28)^{0.25} \\
& + 57.47639\left[(V23)(V8)(V9)\right]^{0.3333} \\
& + 25.18146(V29)^{0.5}(V8)^{0.55} \\
& + 5.87149(V35)\left[(V8)^{0.55} \text{ or } (v12)^{0.55} \text{ or } (V59)^{0.55}\right] \\
& + 7.96547(V43)\left[(V8)^{0.55} \text{ or } (v12)^{0.55} \text{ or } (V59)^{0.55}\right] \Big) \\
\times \Big(& \; 0.73397 \\
& + 0.19580(V61) \\
& - 0.10265(V62) \\
& + 0.16413(V19)/366 \\
& + 0.00973(V21) \\
& + 0.28876(V77) \\
& + 0.09277(V86) \Big)
\end{aligned}
$$

ECONOMIC VARIABLES

(TOTAL = V89+V91+V93+V95+V97+V99+V103+V107+0.00001)

The number 0.00001 was used to prevent the indeterminate figure 0/0 from occuring, which would have prevented the computer from operating on the data.

This model was used to calculate the expected cost of case 137, Crown Offices, Cardiff for which the actual cost of the boiler house and building heating installation was £109 529.

$59.95960(2200)^{0.85}$	41 571.6
$+\ 25.00131(2200)^{0.85}(1914.49/1949.21001)$	17 037.3
$+\ 101.84609(2200)^{0.85}(0/1949.21001)$	0.0
$+\ 33.26266(2200)^{0.85}(0/1949.21001)$	0.0
$-\ 28.69273(2200)^{0.85}(0/1949.21001)$	0.0
$-\ 53.41300(2200)^{0.85}(0/1949.21001)$	0.0
$+\ 172.66727(2)^{0.2}(3810)^{0.55}$	18 488.9
$+\ 231.17644(0)^{0.2}(0)^{0.55}$	0.0
$+\ 401.92386(4390)^{0.25}$	3 271.4
$+\ 25.18146(0)^{0.5}(3810)^{0.55}$	0.0
$+\ 57.47639(0)^{0.3333}(0)^{0.3333}(0)^{0.3333}$	0.0
$+\ 5.87149(6)(3810)^{0.55}$	3 283.9
$+\ 7.96547(10)(3810)^{0.55}$	7 425.1
	91 078.2

x

0.73397	0.73397
$+\ 0.19580(0)$	0.0
$-\ 0.10265(0)$	0.0
$+\ 0.17150(62)/366$	0.02905
$+\ 0.00973(32)$	0.31136
$+\ 0.28876(0)$	0.0
$+\ 0.09277(1)$	0.09277
	1.16715

TOTAL COST = £91 078.2 x 1.16715 = £106 310.00