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Summary The principal incentive for adopting energy efficiency measures is financial. Calculations of energy savings are complicated by the interactions between measures, and their cost effectiveness depends on the price of energy and therefore on the assumed energy source. This paper outlines a plan of work which, by taking account of these factors, minimises abortive work. The plan is illustrated by its application to the Wansbeck District General Hospital, in Northumberland, which is being designed to save nearly 60% of the normal delivered energy consumption.

Selection of energy efficiency measures and their application to Wansbeck General Hospital

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1 Energy efficiency

In engineering language, we are used to the term 'efficiency' expressing a ratio of useful energy output to total energy input. The ratio is always less than unity but designers of, for instance, electric motors strive to approach it as closely as is economically possible.

In a building there is no measure of useful energy output to compare with total energy input, so building energy efficiency cannot be expressed by a simple and precise measure such as a percentage. The word is used to include:

- conservation measures, namely those measures which reduce energy losses and therefore the consumption of energy. Principal measures can be sub-divided into: building design factors comprising, for instance, shelter (by landscaping), orientation, fenestration, shape, thermal insulation and mass, and engineering services design factors comprising systems and components but excluding energy recovery or primary energy conversion sources;
- ambient energy measures, namely the use of ambient energy to supply part of the energy needs;
- heat recovery measures, namely the recovery and reintroduction of heat from exhaust air and waste water;
- primary energy conversion measures for the production of heat and power separately or in combination.

2 Criteria for the adoption of energy efficiency measures

The pressures for saving energy may arise from considerations of social responsibility, political strategy or economic incentive or all of these, but the latter is usually the determining factor.

Cost effectiveness may be expressed in a variety of ways but that advocated for use in the public sector is *benefit to cost ratio* or BCR. For an energy measure:

$$\text{BCR} = \frac{\text{NPV lifetime savings} - \text{NPV lifetime costs}}{\text{NPV of capital cost}}$$

where NPV is net present value, lifetime is the life of the building, lifetime savings are the value of energy savings attributable to the measure, lifetime costs are the additional costs of, e.g. maintenance or replacement attributable to the measure together with any energy costs attributable to it, and capital cost is the installed cost of the measure including fees.

If the BCR is exactly 1.0 the measure will just pay for itself in the lifetime of the project. Sometimes it may be justifiable to set a criterion significantly greater than 1.0 for the adoption of a measure, but in a research and development project a projected BCR of 1.0 or even a little lower may justify the inclusion of the measure to assess its performance by experience. It is, however, usual to test the effect of different fuel price trends in relation to other costs.

It could be argued that energy savings should be judged in terms of primary energy savings rather than the economics of delivered energy. Happily, however, the methods are not in serious conflict as delivered energy prices of fuels and the primary energy fuel factors attributable to them are closely related (Figure 1). In general, therefore, energy efficiency measures, in whichever category previously mentioned,

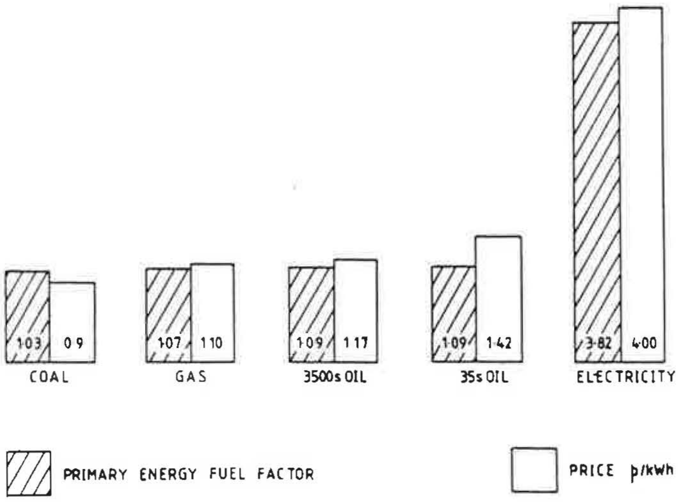

Figure 1 Delivered energy prices of fuels and primary energy fuel factors attributable to them

† The paper was presented at the 1987 CIBSE Technical Conference.

which are found to be economically viable, are likely to serve social and private interest alike and they may properly be selected using economic criteria for effectiveness.

3 The interactive nature of energy efficiency measures

It is essential to check what effect the adoption of one measure might have on the effectiveness of another if abortive work is to be avoided.

Interactions can be explored by the use of a matrix such as Figure 2. It lists both horizontally and vertically building and engineering design factors comprising elements and characteristics in which changes may be made in the interest of energy efficiency. All possible combinations by pairs of the various design factors appear in the squares to the right of the matrix diagonal and a cross denotes an interaction between a pair.

For every pair of factors which is found to interact there is a requirement to take account of the saving made by one factor on that which may be made by the other. Taking as an example from the figure, building insulation—design factor 1—affects the space heating requirements and consequently the quantity of water in the relevant distribution systems so that the effects of change in pump energy (19) and pipe insulation (11) alter; also the need for heat from all sources, namely heat recovery from incineration (19), CHP (20), the boiler (23) and therefore also the heat store (20) also alters.

It follows that the value of savings made, e.g. by boiler efficiency improvements, cannot be ascertained before the building insulation has been settled. It also follows that the value of savings resulting from improvements in building insulation will be reduced when the cost of useful heat is reduced by an increase in boiler efficiency. With the numerous interactions illustrated by Figure 1, it is clear that some study plan is needed if seemingly endless recalculations are to be avoided. If, as was required in the two low-energy hospital studies[1,2] the BCR for each measure which has an effect on thermal energy consumption has to be calculated separately for coal, gas, and oil and that for each fuel three different price trends must each be calculated separately, it becomes essential to ensure that the task is kept proportionate to the time and cost budget of the study.

4 Procedures adopted in the low-energy hospital studies

In summary the study procedure adopted for the first low energy hospital study[1] was:

(*a*) for the functional content required, assuming the annual weather data applicable to Kew in 1967, and the standards of design applicable at 1980, to calculate the annual energy consumption—termed the *datum energy requirement*

(*b*) to study and apply conservation measures which have a BCR of at least 1.0 and ascertain the *reduced energy requirement*

		Building insulation 1	Area of glazing 2	Single/double glazing 3	Building mass 4	Building orientation 5	Landscaping 6	Air infiltration 7	Mechanical ventilation 8	Fan efficiency 9	Pump efficiency 10	Pipe insulation 11	Lamp efficiency 12	Lighting control gear efficiency 13	Lighting auto switching 14	Catering schedule 15	Catering equipment efficiency 16	Humidification 17	Heat recovery exhaust air 18	Incineration and heat recovery 19	CHP 20	Heat store 21	WTG 22	Boiler efficiency 23
Building insulation	1										x	x								x	x	x		x
Area of glazing	2			x	x	x	x		x	x	x	x	x	x	x					x	x	x		x
Single/double glazing	3										x	x								x	x	x		x
Building mass	4					x			x	x												x		
Building orientation	5						x		x	x														
Landscaping	6							x					x	x	x									
Air infiltration	7								x	x									x	x	x	x		x
Mechanical ventilation	8									x			x	x	x				x	x	x	x		x
Fan efficiency	9																				x		x	
Pump efficiency	10																				x		x	
Pipe insulation	11																			x	x	x		x
Lamp efficiency	12														x								x	x
Lighting control gear efficiency	13														x								x	x
Lighting auto switching	14																		x					x
Catering schedule	15																x		x		x			x
Catering equipment efficiency	16																		x	x	x	x	x	x
Humidification	17																				x			
Heat recovery exhaust air	18																			x	x	x		x
Incineration and heat recovery	19																				x	x		x
CHP	20																					x	x	x
Heat store	21																							x
WTG	22																							
Boiler efficiency	23																							

Figure 2 Matrix of interactions between energy design factors

(*c*) to study and apply such ambient energy, heat recovery and on-site generation measures as have a BCR of at least 1.0 to ascertain the *resultant energy requirement*.

The same outline procedure was adopted in the second low-energy hospital study(2) in which it was also decided to test the BCR of building design factors (Section 1) before applying engineering system design factors. The reasons for so doing were to minimise the building's basic need for energy, to keep the study manageable by reducing some of the permutations theoretically possible, and in recognition of the fact that since most building elements would not be economically changeable in the life of the building (whereas the engineering systems and components could be expected to be changed several times) it was reasonable to give them priority of consideration.

After completing the study, in the evaluation and selection of measures for the design of the Wansbeck General Hospital in which some of the functional content and operational policies varied from those in the study model, it was realised that the approach could be further refined in evaluating measures against different fuels. The approach recommended is to evaluate each energy saving measure with a thermal implication against the fuel and boiler plant which would be the optimum choice at the time of the introduction of the measure. This approach is illustrated in the following sections of this paper by the example of Wansbeck General Hospital.

5 Study procedure for measures with thermal effects

5.1 Initial fuel appraisal

As part of the design process for any building, it is customary to assess which practicable fuel will be the most economic. The assessment should include not only the cost of the fuel but the different costs of fuel delivery arrangements, space, plant, and disposal systems including chimney and ash removal if any. The analysis can take all these factors into account by expressing the costs in terms of present value.

Figure 3(*a*) illustrates the components of the datum energy requirement of Wansbeck General Hospital, comprising 9 067 000 kWh of fuel and 3 118 000 kWh of electricity. To meet this demand it was assessed that there should be two duty boilers and one standby boiler, all of 1.5 MW rating. The starting fuel prices per kWh on which the cost appraisals were based were: coal, 0.945 p; gas, 1.155 p; 3500 s oil, 1.490 p; 35 s oil, 1.230 p and they were deemed to change in accordance with Department of Energy forecasts. The discount rate taken for capital costs was 5%. The complete fuel cost appraisal included fluidised bed, underfeed stoker, coking stoker and fixed grate stoker, coal fired boilers, 35 s and 3500 s oil fired boilers as well as gas fired boilers. For the sake of brevity, Table 1 lists only the cheapest coal fired option—the underfeed stoker—together with the gas fired boiler, the NPV of the lifetime costs of which were lower than those of either of the oil fired options.

The table is seen to favour the coal-fired option and it follows that the cost effectiveness of any thermal efficiency measure considered at this stage should be tested against the use of a coal-fired plant. The financial consequences of the thermal effects of other measures such as lighting efficiency, whether stemming from window or lighting installation design, should also be based on coal.

5.2 Order of application of conservation (static) measures

As explained in Section 4, building design measures were considered first and followed by engineering system design measures. It is not the object of this paper to describe these measures in detail but in broad terms they included:

(*a*) changes to the building cross section, including the fenestration, insulation, air tightness and mass

(*b*) reduction of distribution losses by improved insulation, replacement of dual duct air conditioning by low-velocity single duct terminal heating and cooling, a completely revised schedule of energy efficient direct fired catering equipment, electrically energised humidification, high

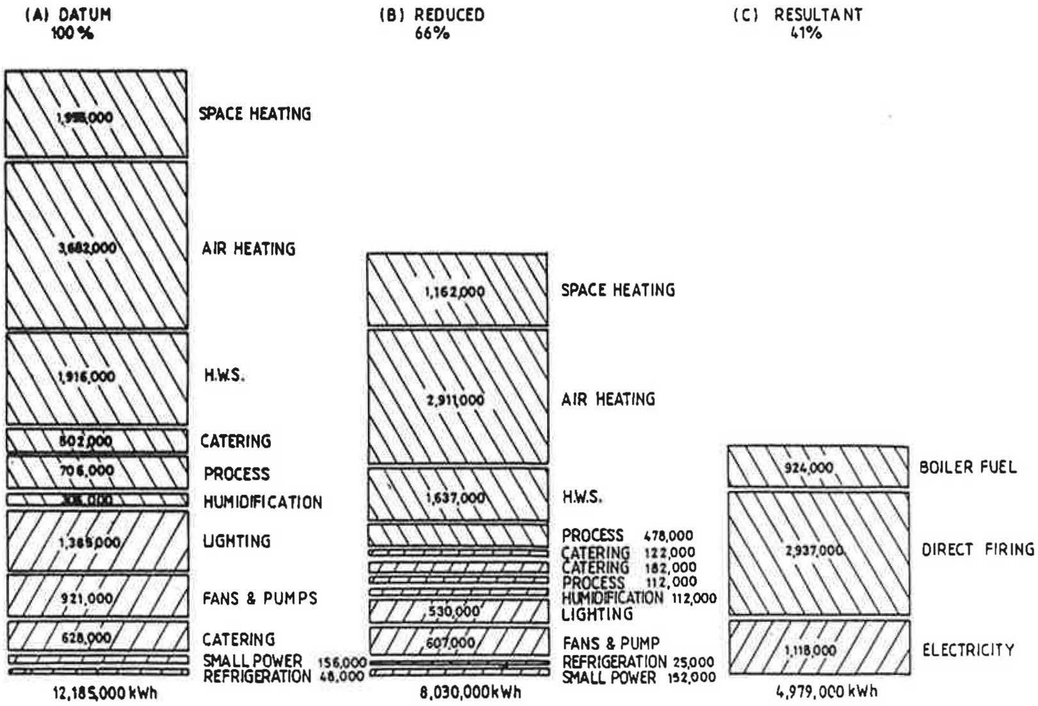

Figure 3 Datum, reduced and resultant annual energy requirements

Table 1 Cost appraisal of boiler plant comprising three 1.5 MW boilers supplying a 'datum energy requirement' of 8360 MWh

Cost (£ NPV)		Fuel	
		Gas	Coal†
Capital cost of boiler installation including supply contribution, building cost etc.		180 192	254 416
Design fees	Pre-contract	26 767	37 969
	Post-contract	8 528	12 466
Intermittent replacement costs		44 507	92 980
Non-fuel operating costs		31 146	208 622
Fuel cost		3 241 991	2 164 829
Total cost		3 533 131	2 771 282

† Underfeed stoker

efficacy lamps with low-loss control gear and low loss fans and pumps.

In category (*a*) the BCR of each measure was calculated individually to enable measures to be ranked in descending order of BCR. The BCR was recalculated where there was an interaction with a preceding measure. Measures whose BCR then fell below 1.0 were discarded.

A similar procedure was adopted for measures in category (*b*), the initial BCR in this case, however, taking account where necessary of the category (*a*) measures already applied.

All these measures had a BCR of 1.0 or better when tested against coal, except the group of building measures which gave a marginally lower figure. The building measures were included on the basis of their providing, among other things, a higher quality environment which was not capable of precise financial evaluation.

5.3 *Second boiler appraisal*

After the adoption of these measures, the annual boiler fuel requirement was reduced from 8 360 000 to 5 710 000 kWh.

Daily load profiles were then calculated for typical winter, summer and mid-season periods. These profiles indicated that the maximum heat demand could be met, with a reasonable margin, by two 1000 kW duty boilers with another as standby.

Table 2 Cost appraisal of boiler plant comprising three 1.0 MW boilers supplying a 'reduced requirement' of 5710 MWh

Cost (£ NPV)		Fuel	
		Gas	Coal†
Capital cost of boiler installation including supply contribution, building cost, etc.		176 307	249 793
Design fees	Pre-contract	26 172	37 261
	Post-contract	8 939	8 639
Intermittent replacement costs		43 012	90 153
Non-fuel operating costs		31 146	172 570
Fuel cost		2 103 610	1 404 679
Total cost		2 389 186	1 963 095

† Underfeed stoker

A second fuel appraisal was then undertaken, the results of which are shown in Table 2. This table shows that the difference between coal- and gas-fired boiler lifetime costs has narrowed but that coal remains the cheaper. It becomes apparent that the application of additional measures, which reduce the boiler fuel requirement further, may cause the choice of fuel to change. As additional measures are applied, therefore, more fuel cost appraisals may be needed.

6 Application of the study procedure to the selection of dynamic measures at Wansbeck General Hospital

6.1 *Measures considered*

The most promising dynamic measures considered for Wansbeck GH were:

- heat recovery from exhaust air by run-around coils or heat pumps or both
- improved methods of waste incineration and heat recovery from it
- combined heat and power generation
- heat storage for use in combination with the above means of heat recovery and the boiler plant
- the generation of electricity by a wind turbine generator (WTG)

Some other measures including heat recovery from liquid wastes and methane collection from hospital sewage were considered but quickly found to be uneconomic.

6.2 *Electricity Tariff*

The North Eastern Electricity Board General Purpose Tariff available to a consumer who does not generate any electricity on site, and applicable at the time of the appraisal, was a two-part Maximum Demand (MD) Tariff which gave an average cost of electricity consumed of approximately 4.2p kWh^{-1}.

Where a consumer generates any electricity on site, whether or not any energy is purchased by the Board from the consumer, the Private Generator and Supplier Tariff is applicable. This tariff contains no MD charge but varies the price per kWh (supplied or purchased) by time of day, day of the week and season. Table 3 is an extract of the salient parts of the tariff.

By using the load profiles, a calculation was made of the effect of applying the supply charges of this tariff to the reduced electricity consumption. It was found that the annual cost of electricity would be increased by nearly 9%. Any on-site generation of electricity would, therefore, first have to overcome this penalty before showing a cost benefit.

6.3 *Standby generation*

All hospitals must be provided with standby generation to meet essential loads. The effect of the Private Generator and Supplier Tariff is to make the supply price of electricity particularly high during daytime winter weekdays but considerably less at other times. It was decided, therefore, to examine the economics of running the standby diesel engine generators during these winter day hours. Since they amount to less than 1000 h y it was considered that the reduction in life of the sets would probably not be more than 5 years. The capital, replacement and maintenance charges to be

Table 3 Extract from North Eastern Electricity Board Private Generator and Supplier Tariff (1986)

Nature of change	Supplies from low voltage general distribution system	Supplies from high voltage substations	
		Where metered at low voltage	Where metered at high voltage
1 Monthly charge	£17	£53	£53
2 Monthly availability charge for each kilovolt ampere of supply capacity	79p	61p	61p
3 *Unit charges*			
(i) *Winter Peak Units* For each unit taken in the Winter Peak Period (at present 1630–1830 h on Mondays to Fridays inclusive in December, January and February)	33p	31p	30p
(ii) *Winter Day Units* For each unit taken in the Winter Day Period (at present 0800–2000 h on Mondays to Fridays from November to February all inclusive but excluding Winter Peak Period hours)	6.97p	6.17p	6.0p
(iii) *Night Units* For each unit taken in the Night Period (at present 0300–0730 h every day of the year)	1.99p	1.87p	1.83p
(iv) *Standard Units* For each unit taken at all other times	3.75p	3.50p	3.40p
4 *Fuel price adjustment* For each penny by which the national fuel price is more or less than 5200p per tonne the unit charges for each month shall be increased or decreased by:	NIL	0.00034p	0.00033p
5 *Reactive power charge* For each lagging kVArh supplied by the Board in excess of 0.5 times the number of kWh supplied each month	0.35p	0.21p	0.15p

brought into the BCR calculation therefore needed only to reflect the charges extra to those which would have been required in any case. The principal additional capital charges arose from synchronising and heat recovery equipment.

6.4 Incineration

As an operational policy not only hospital waste but also home dialysis and other waste will be incinerated at the hospital. The quantity and calorific value of such waste will thus both be enhanced. There will be only one incinerator during the first 300 bed phase of the hospital.

6.5 Effect of possible measures on boiler plant size

Of the possible measures listed in Section 6.1, it was considered that the cost of a measure which could be relied upon as being available at times of peak heat demand could be credited with the value of reductions in boiler plant size as well as fuel. During such times of peak heat demand, exhaust air heat recovery would be more effectively achieved by run-around coils rather than by heat pumps and at least 85% of the recovery potential of them should be available, so they could be credited with boiler savings. Since the use of the standby generators during winter day hours excludes weekends, when the heat recoverable from them would have to be met by the boiler plant, and there would be only one incinerator which could be out of service for a variety of reasons, it was decided to credit the benefits attributable to these measures with fuel savings only.

7 Application of the measures

Preliminary calculations based on each measure applied independently of any other indicated a ranking of BCR in descending order: (*a*) exhaust air heat recovery, (*b*) incineration with heat recovery, (*c*) use of standby generation with heat recovery during winter day hours, (*d*) wind turbine generator. The measures were therefore tested using that order of application, noting their effects of the typical daily reduced load profiles as illustrated in Figures 4–6.

7.1 Exhaust air heat recovery

The simplest and, in capital cost terms, cheapest method of exhaust air heat recovery is provided by run-around coils which were therefore considered first. The amount of heat recoverable by them clearly changes with season; it is greatest in the coldest weather.

Table 4 Key to Figures 4–6

	Heat utilised from run-around coils
	Heat utilised from incinerator
	Heat abstracted from heat store
	Electricity generated by and heat utilised from 86 kW gas engine generator
	Electricity generated by and heat utilised from 138 kW diesel engine generator
	Electricity generated by and heat utilised from 211 kW diesel engine generator
	Electricity generated by wind turbine generator

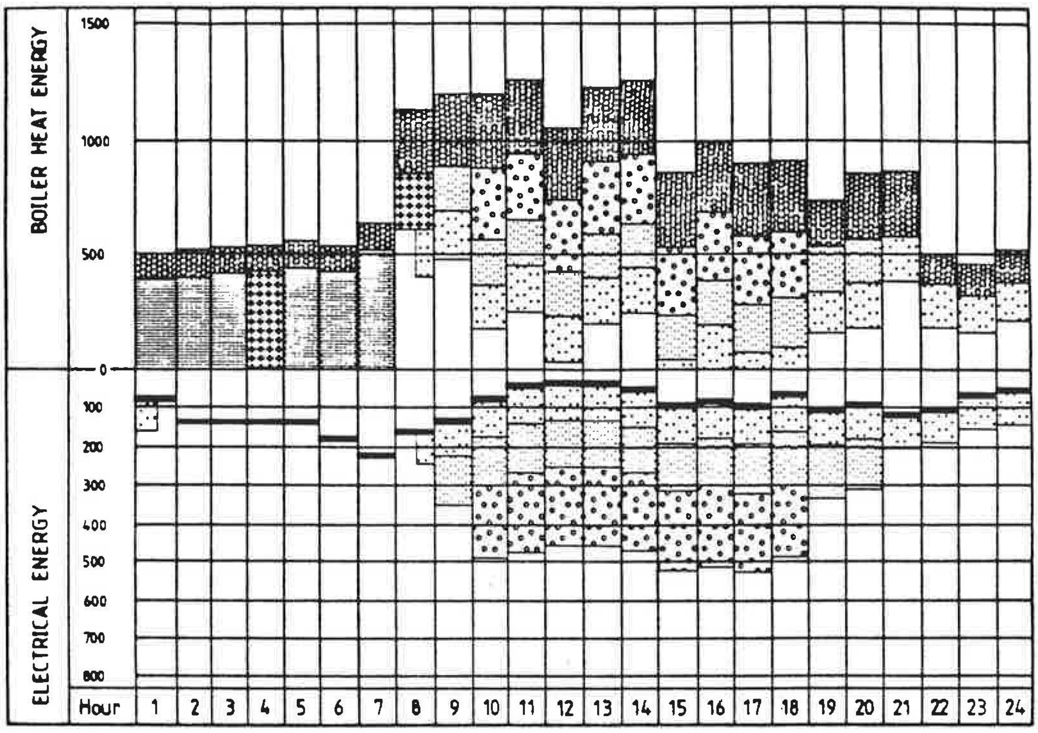

Figure 4 Daily reduced load profile for mid winter (December, January, February) with effect of dynamic energy measures superimposed

Table 5 Energy and BCR appraisal of run-around coils

Units of energy ($kWh\,y^{-1}$)		Fuel cost implications: Central projection (£ NPV)			Dynamic boiler fuel savings (£ NPV)	Non-fuel revenue costs (£ NPV)	Net revenue benefits (£ NPV)	Total capital costs (£ NPV)	BCR
Fuel	Elect.	Fuel	Elect.	Total					
(1 693 080)	146 200	(409 285)	101 612	(307 673)	129 182	31 486	40 586	57 979	6.99

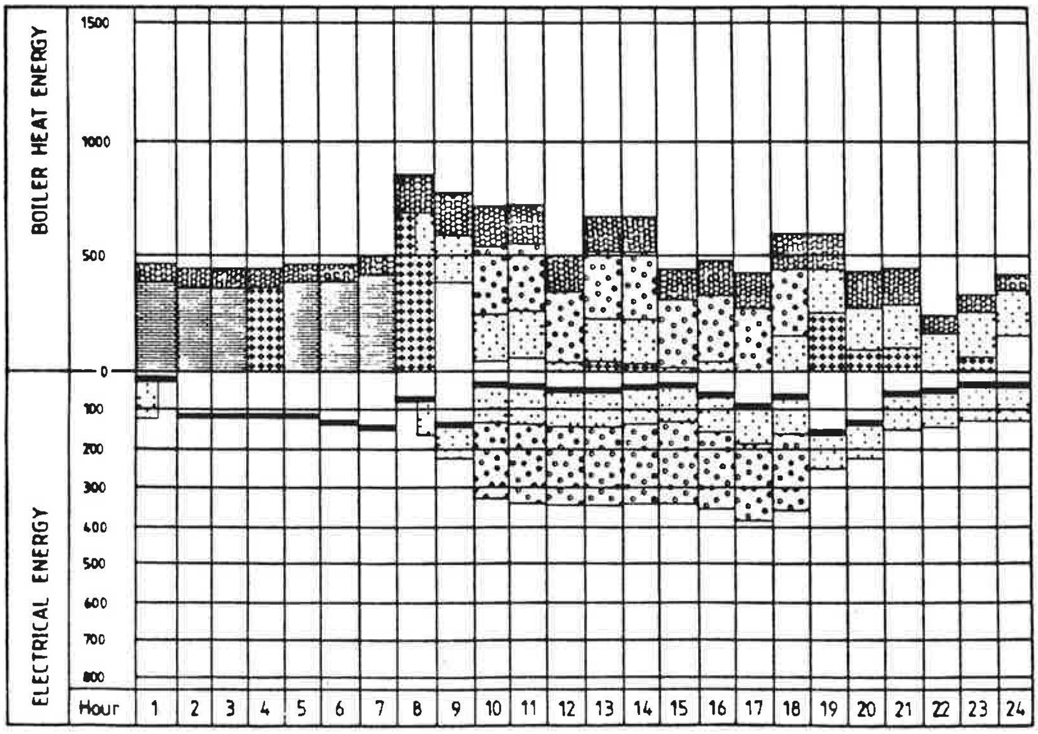

Figure 5 Daily reduced load profile for mid season (November) with effect of dynamic energy measures superimposed

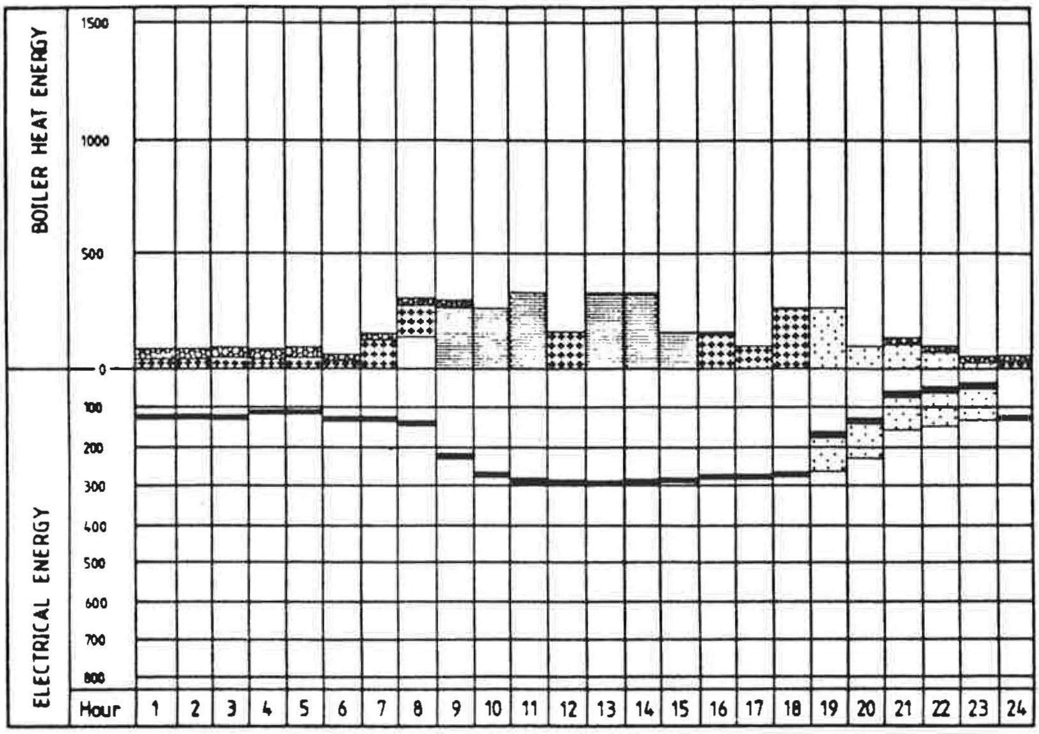

Figure 6 Daily reduced load profile for mid summer with effect of dynamic energy measures superimposed

A computer programme devised in-house was used to determine the savings in boiler fuel and consumption of electrical energy. The appraisal is shown in Table 5 where the BCR of the measure is seen to be 6.99. The effects on the typical daily reduced load profiles are illustrated in Figures 4–6. It will be noted that all the heat can be used without recourse to heat storage.

7.2 *Incineration*

Hospital waste is estimated to amount to 750 kg day^{-1} and other waste, a further 566 kg day^{-1}, making 1316 kg day^{-1} in total.

The datum incinerator is a conventional gas-fired plant without heat recovery. Table 6 analyses the effects of equipping such an incinerator with heat recovery, the use of a fuelless incinerator with and without heat recovery and a low fuel incinerator, also with and without heat recovery. The highest BCR is achieved by using a conventional incinerator with heat recovery but a greater energy saving is achieved by the fuelless incinerator with heat recovery. Operationally the fuelless incinerator has the following advantages:

(*a*) In the event of breakdown of the heat recovery boiler, the fuelless plant will continue to save energy.

(*b*) It is batch loaded and, apart from the loading operation, does not require continuous attendance. It can be programmed to burn at any selected time after loading.

Characteristic (*b*) has the particular advantage that a plant used during the day would reduce the opportunity for heat

Table 6 Energy and BCR appraisal of incineration options

Incinerator type	Capital cost (£ NPV)	Fees (£ NPV)		Fuel used (kWh y^{-1})		Boiler fuel saved (kWh y^{-1})	Fuel cost (£ NPV)		Non-fuel revenue cost (£ NPV)	Inter. replac. boiler (£ NPV)	Value of fuel cost saving (£ NPV)	Total revenue (£ NPV)	BCR
		Pre Cont.	Post Cont.	Elec.	Gas		Elec.	Gas					
Conventional without HR	86 000	12 762	4 212	28 000	466 000	—	23 309	166 814	134 455	80 998	—	405 576	—
Conventional with HR	116 824	17 336	5 722	28 000	466 000	1 428 480	23 309	166 814	136 800	101 932	325 457	302 178	8.85
Fuelless without HR	104 000	15 434	5 096	28 640	—	—	23 842	—	141 555	95 600	—	144 579	6.7
Fuelless with HR	134 824	20 008	6 606	28 640	—	1 208 492	23 842	—	145 000	116 534	275 335	395 535	6.76
Low fuel without HR	115 866	17 195	5 677	27 766	346 000	—	23 114	123 857	138 045	106 324	—	14 236	0.4
Low fuel with HR	146 690	21 769	7 187	27 766	346 000	1 399 173	23 114	123 857	145 000	127 258	310 278	296 625	4.08

The boiler fuel savings in the table are the practical savings taking account of the need for heat at the time heat is recovered and the size of the heat store.

recovery from combined heat and power (CHP) sets for which the tariff provides only a daytime running incentive. The fuelless incinerator was, therefore, selected and, by agreement with the client, it will be programmed to burn two loads on weekday nights in winter and mid-season but during the day in summer.

The effects of this on the daily load profiles are shown in Figures 4–6. It will be noted that the demand for heat will sometimes be less than that recovered. The great majority of the excess will be absorbed by an 800 kWh high-grade water heat store and used shortly afterwards. The operation of the heat store is described in Section 8.

7.3 Use of standby generators during winter day hours

Standby electrical requirements can be met by two 211 kW diesel generators each capable of providing 60% of the essential load. The highest charges for electricity are made between 8 am and 8 pm on weekdays during November, December, January and February with special peak charges between 4.30 pm and 6.30 pm in the latter three months. The load profiles illustrate that the electrical output from both sets could be wholly used for most of the 12 h period in December, January and February but the output of only one machine could be used in November. All the recovered heat could be used in these periods.

With the value of the thermal energy savings calculated against coal, a BCR of approximately 1.6 was calculated. Before adopting the measure in this form, however, consideration was given to a development of it.

Equivalent on-site generation capacity could be provided by replacing one of the 211 kW diesel engine driven generators by a 125 kW set plus an 86 kW gas engine driven generator which it may be economical to operate as a base load machine over longer periods. Table 7 shows the cost appraisal including a BCR of 1.63 for standby generators comprising one 211 kW and one 138 kW diesel generator only, with thermal energy savings assessed against a coal fired boiler plant. The total fuel savings now being made necessitate a reassessment of the optimum boiler plant before considering the gas engine generator.

7.4 Boiler reappraisal

The resultant annual heat requirement after the application of the foregoing measures is reduced to 1 539 000 kWh. The appropriate boiler capacity to cater for weekend use and the possible breakdown of the 211 kW diesel set and its heat recovery equipment, together with a reasonable margin for extreme cold would be two 600 kW duty boilers with one standby.

Examination of the load profiles corresponding to this consumption shows that the boiler load is very variable and, even with a heat store, it is unlikely that a coal fired boiler plant would return an average annual efficiency of 70% and it may well be much less. On the other hand, gas boilers of 600 kW rating can be modular and may well return average annual efficiencies of 80%.

Table 8 Fuel appraisal based on three 600 kW boilers needed to meet an energy requirement of 1 539 000 kWh

Cost (£ NPV)		Fuel: Gas	Fuel: Coal
Capital cost of boiler installation including supply contribution		171 694	244 430
Design fees	Pre-contract	25 478	36 273
	Post-contract	8 412	11 977
Intermittent replacement costs		42 408	109 153
Non-fuel operating costs		31 146	134 520
Fuel cost		681 826	506 957
Total cost		960 964	1 043 310

Table 8 shows the comparison of coal and gas fired boilers of this size with assumed average efficiencies of 70% and 80% respectively. It is now seen that even attributing what may be an optimistic efficiency to the coal fired plant, gas becomes the preferred fuel. The fuel savings attributable to any further measure should therefore now be evaluated against gas.

7.5 Use of a base load gas engine generator

Base load gas engine generators are available as package units. An 86 kW synchronous engine generator set will provide 180 kW of high-grade recoverable heat. The load profiles in Figures 4–6 show the opportunities for running such a set in conjunction with the diesel generators. It is estimated that, without exporting electricity, when used in conjunction with an 800 kWh heat store, the set could be run for well over 5000 h y^{-1}.

It is assessed that this machine may be credited with boiler capacity savings (the size would be reduced from 600 to 500 kW) because if it were not available, one of the diesel engines—which have not been credited with such savings—would be available. One this basis Table 9 shows the BCR of such a gas engine generator to be 1.29 when assessed against gas as the boiler fuel. For comparison purposes, the BCR against coal is also given and is shown to be only 0.6. This clearly demonstrates the importance of appraising each measure financially against the boiler fuel appropriate at the time of its application.

7.6 Use of a wind turbine generator

The Wansbeck hospital will be within sight of the sea and windmills have been used in the area in the past. Wind

Table 7 Energy and BCR appraisal of co-generation using one 211 kW and one 138 kW standby generators

Units of energy ($kWh\ y^{-1}$): Fossil	Units of energy ($kWh\ y^{-1}$): Elect.	Fuel costs (£ NPV): Fossil	Fuel costs (£ NPV): Elect.	Non-fuel revenue costs (£ NPV)	Total revenue costs (£ NPV)	Total capital costs (£ NPV)	BCR
+385 440	−287 037	299 292	(495 458)	104 163	(92 003)	56 526	1.628

Table 9 Energy and BCR appraisal of co-generation using 86 kW gas engine generator

Capital and fees (£ NPV)	Gas used		Electricity generated		Boiler fuel saved		Dynamic boiler savings (£ NPV)	Inter. repl. costs (£ NPV)	Non-fuel revenue costs (£ NPV)	Total revenue savings (£ NPV)	BCR
	(kWh)	(£ NPV)	(kWh)	(£ NPV)	(kWh)	(£ NPV)					
57 685†	1 830 270†	655 180†	465 690†	399 317†	1 299 600†	296 094†	99 159†	27 340†	77 635†	34 415†	0.6†
57 685‡	1 830 270‡	655 180‡	465 690‡	399 317‡	1 203 333‡	430 756‡	4 528‡	27 340‡	77 635‡	74 446‡	1.29‡

† Coal fired boilers.
‡ Gas fired boilers.

measurements taken at a nearby recording station were compared with measurements taken on the site and a forecast made of annual wind speed and direction profiles at the WTG location. Analysis of the results indicates that a 55 kW/20 kW wind turbine with a hub height of 22.5 m coupled to an asynchronous generator would be cost effective as Table 10 illustrates.

Clearly the WTG output will vary between zero and 55 kW. Its average will be about 16 kW and it is this output which is shown in Figures 3–5 though the annual wind profile shows a minimum of 7 kW average in August and a maximum of 28 kW average in March. Since the measure is applied after the introduction of on-site generation, the BCR was calculated by valuing the energy generated in accordance with the NEEB Private Generator and Supplier Tariff and by reference to the annual wind profile for the site. No account was taken of the average daily wind profile which would have increased the proportion of units valued at daytime charging rates. The BCR so calculated was 1.47.

7.7 Resultant energy requirement

The boiler fuel requirement is now reduced to 925 000 kWh/y^{-1}. The load profiles demonstrate that the boiler fuel requirements on weekdays are negligible in summer, very small in mid season and very variable in winter. There is no case for installing heat pumps or solar heating devices which would be most effective in the summer and mid-season periods. No other dynamic measures merit consideration at this stage and Figure 3(c) therefore represents the resultant energy requirement which is approximately 41% of the datum requirement.

7.8 Cumulative BCR

The cumulative BCR of all measures was ascertained to be 1.88, all those except that of the gas engine generator being calculated against coal as the fuel. It is relevant to consider whether at this stage all BCRs should be recalculated against gas and thereby enhanced. It is the author's view that they should not. All measures were justified step by step against the most economic fuel at the time of their being applied and this remains their justification.

Had any conservation measures been rejected earlier in the study because they were found not to be quite cost effective when appraised against coal, they could be re-examined at this stage to ascertain whether, now that gas has become the appropriate fuel, they would be cost effective. It would, however, be important to test them against the resultant energy requirement and load profiles as their relevance may have changed.

7.9 Energy flows

The simplified Sankey diagrams (Figures 7, 8 and 9) illustrate the progression from datum to resultant energy flows. It will be noted that the reduced energy requirement has to be met: the dynamic measures introduced after the conservation measures provide only an alternative means of supplying this energy requirement.

8 System design

The primary purpose of this paper is to illustrate the procedure for appraising and applying energy measures. When several dynamic measures are applied, the design of both heating and electrical systems must be practicable.

8.1 Thermal energy systems

The thermal energy systems may be energised at any one time by the boilers, one or more of the gas engine generators, the incinerator, or by any combination of the above. Whereas the output from the boilers can be varied, that from each generator and from the incinerator will be virtually fixed. It is mainly for this latter reason that a heat store is needed—to absorb surplus heat and release it when it is needed. During the times when these items of plant are scheduled to run, therefore, they become the basic heat producers and the boiler is used to supply any residual requirements.

The heating system diagram of Figure 10 shows the gas boilers and the heat recovery systems from the generators

Table 10 Energy and BCR appraisal of one 55 kW wind turbine generator

Units of energy (kWh y^{-1})		Fuel costs		Non-fuel revenue costs (£ NPV)	Total revenue costs (£ NPV)	Total capital costs (£ NPV)	BCR
Fossil	Elect.	Fossil (£ PV)	Elect. (£ PV)				
—	−146 900	—	(129 158)	26 687	(102 471)	69 813	1.468

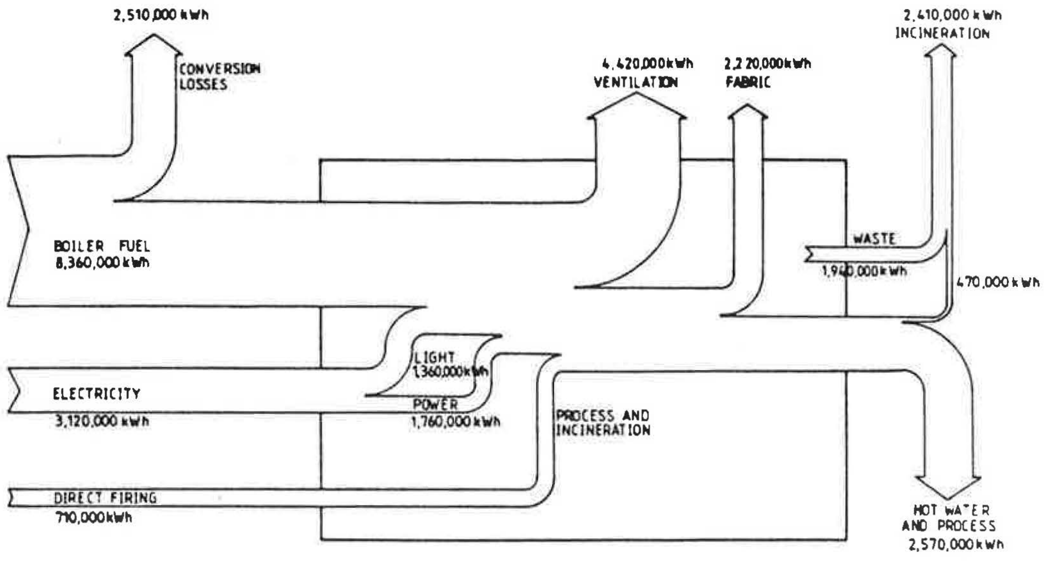

Figure 7 Simplified Sankey diagram for datum energy flows

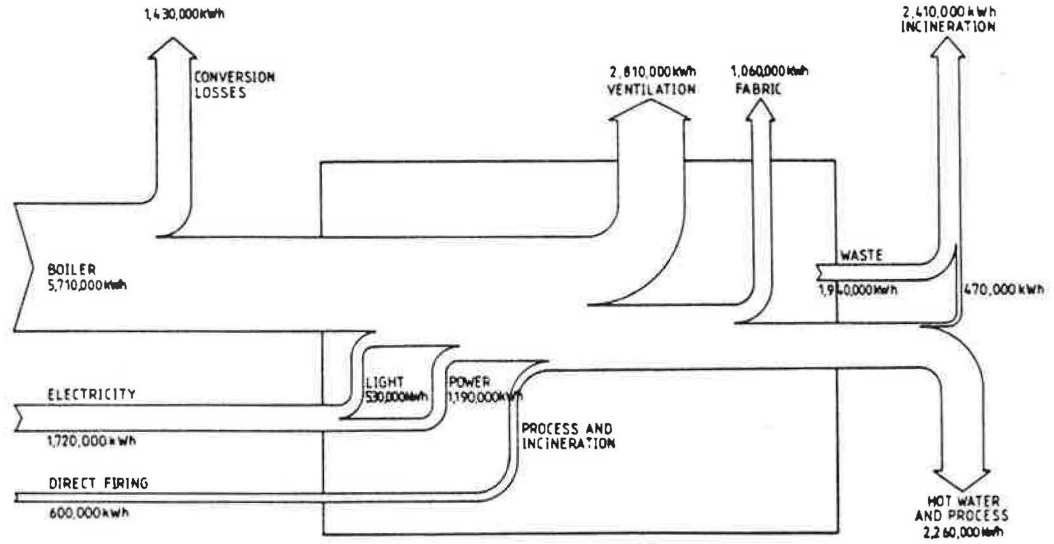

Figure 8 Simplified Sankey diagram for restricted energy flows

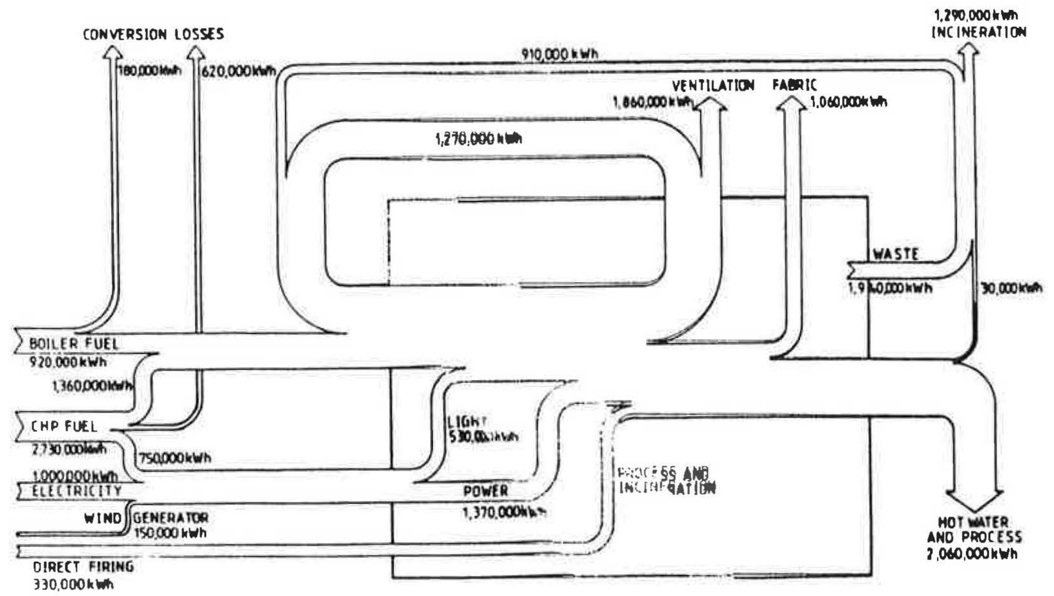

Figure 9 Simplified Sankey diagram for resultant energy flows

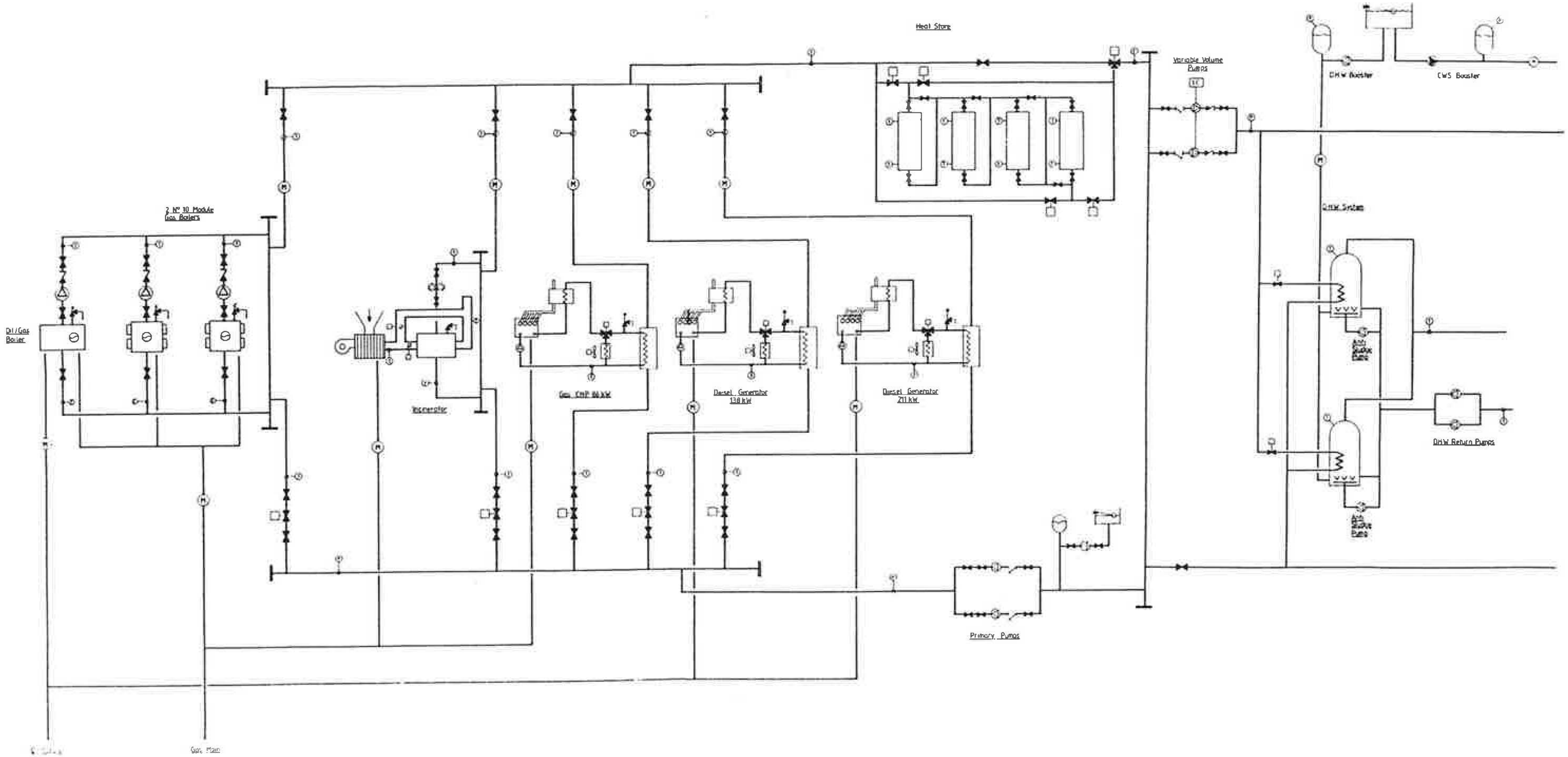

Figure 10 Main heating system diagram

and incinerator connected in parallel. The water flow through each is balanced so that at maximum output each produces a temperature rise of 10°C.

Each machine has a two-port valve regulating the water flow between zero and the maximum. This valve is controlled from a flow sensor so that as the heat production of the machine decreases, the water flow is reduced to maintain a constant flow temperature. A two-port valve in the boiler circuit, controlled from a pressure sensor in the header, maintains a constant system flow rate by passing the balance through the boilers when the output of the other heat producing equipment reduces. The boiler firing is controlled by a temperature sensor in the main flow pipe sensing the mixed condition so that the boiler fires only when the demand for heat exceeds the production by other equipment. The nominal flow and return temperatures are 80°C and 70°C but when the system demand for heat falls, the return temperature rises above 70°C and is raised by 10°C through the heat producing plant. This water then mixes with return water passing through the boilers and results in an 80°C flow at all loads. At zero heat load the system flow temperature will rise to 90°C thus maximising the capacity of the heat store. The store is arranged so that it can be charged by or discharge into the flow line and is controlled so to maintain a constant flow temperature to the rest of the system.

8.2 Electrical system

Figure 11 illustrates the main electrical system. The engine generators are all synchronous machines which will run in parallel with one another and with the public supply during normal conditions. The WTG is an asynchronous generator the speed of which will be controlled by the system to which it is connected. The mains supply could fail at times when no engine generators are running or when any combination of them is running. In either case the WTG could be running or not, depending on the wind.

In either event, the hospital bus-bars must be isolated from the supply and the output of the engine generators automatically applied to the essential bus-bar section. Should mains failure occur when no on-site generation is occurring, a no-voltage relay will separate the essential from the non-essential bus-bars in the conventional way. Should failure occur when on-site generation is taking place such a relay would not detect the interruption as the generators would attempt to maintain the voltage. Several relays have been developed for detecting mains failure under these circumstances such as reactive export error detectors and rate of change of frequency relays. A suitable fast-acting relay to cater for this condition will be used to isolate the mains and hence protect the generators.

For reasons of stability, the WTG will be tripped out whenever the mains fail.

Restoration of mains supplies will be dealt with in the normal way—namely all on-site generation will be disconnected and all hospital circuits re-energised from the mains. Any on-site generation required will then be reconnected in accordance with the time schedule.

The heat recovery systems from the engines will have to operate whenever the engines are run to keep them cool. If they have to run when this heat cannot be used, it will be dissipated through a heat dumping radiator on the roof of the energy centre.

9 Conclusion

It is hoped that this paper has demonstrated ways in which interacting energy efficiency measures can be identified and financially appraised in an orderly way. In summary it recommends the adoption of the following procedure:

(*a*) Select the most appropriate boiler plant and fuel before any energy efficiency measures are applied.

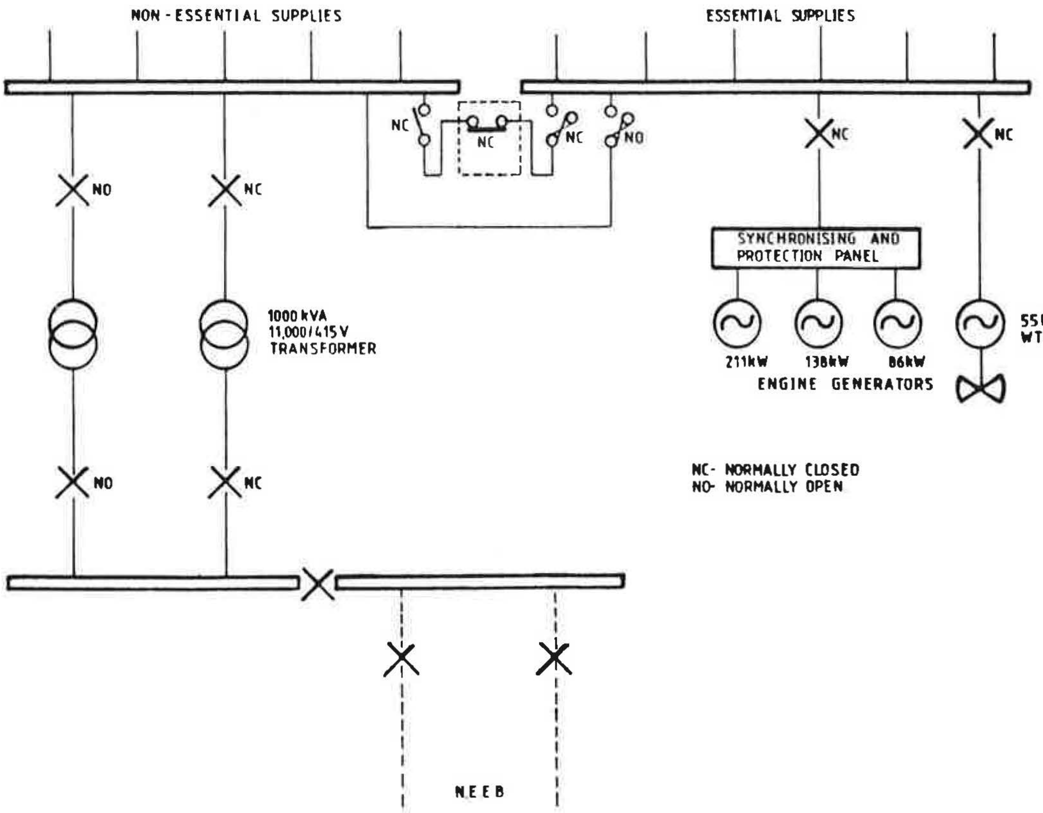

Figure 11 Main heating system diagram

(*b*) Identify by means of a design element matrix all significant interactions between measures.

(*c*) Classify measures into conservation (static) and dynamic and, to reduce the calculation burden, consider the subdivision of conservation measures into building and engineering measures.

(*d*) In each classification in turn, rank each measure considered in terms of its BCR (or other financial rating) calculated against the fuel determined in (*a*), as if the measure were applied on its own.

(*e*) Apply measures in each classification in the order of their financial ranking but modify the financial rating if it is influenced by a preceding measure and discard any measure whose rating then falls below the accepted criterion (e.g. a BCR of 1.0).

(*f*) As measures are adopted, particularly those of a dynamic nature, review the magnitude and pattern of heat demand and reappraise as necessary the most appropriate boiler fuel.

(*g*) If it becomes economic to change the boiler fuel, test the financial viability of succeeding measures against the changed fuel.

(*h*) Credit measures which enable the size or type of boiler plant to be changed with savings in such plant as well as with fuel cost savings.

In the example of Wansbeck GH the change of optimum fuel at a particular stage made viable a particular measure, the gas engine generator, which would not have been viable had it been appraised against the original fuel. Likewise, the introduction of a wind turbine generator became viable only because the change of electricity tariff, which follows the introduction of any on-site generation in the NEEB region, had been justified by the cogeneration measures introduced beforehand. Although several dynamic measures are required to work in combination, the system designs required are not overcomplicated.

10 Postscript

The purpose of this paper has been to formulate and, by the example of Wansbeck General Hospital, also to illustrate a plan for undertaking a comprehensive energy study. The methods of making the energy calculations will be found in the references quoted. The DHSS intends to undertake an extensive programme of monitoring and evaluation of the energy saving measures in this demonstration project. The findings will subsequently be used to determine appropriate guidance for the National Health Service.

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