PROPOSED UEA HEAT PUMP - October 1981

CONTENTS

A. UNIVERSITY PLAIN: SUMMERTIME HEATING - B. Mitchell

1. Introduction

A paper was produced in August 1981 giving the broad outline of a scheme to provide heating to residences by means of Heat Pumps in Summer, enabling the main Boilerhouse to be shut down. Since that time, more information has become available and the present report is intended to supersede the former.

2. Details of the Proposal

a) Present arrangement

The main boilerhouse operates the whole year round apart from a two-week shutdown for maintenance purposes, usually early in July. The boilers produce high temperature hot water in a closed circuit which passes throughout the site via pipes which are about 50% above ground, exposed but well insulated.

During Summer, the water circulation is maintained mainly to provide domestic hot water services, heating generally being turned off during June, July, August and part of September. Heating is provided during these months on demand only in residences and special areas like the Biology Greenhouse. The residences are particularly important because of the need to provide an acceptable venue for conferences during the summer vacation, as well as normal term-time conditions for students.

During the Summer shutdown, domestic hot water services are provided in residences and some academic buildings by means of standby electric water heaters.

These are provided as listed

Arts I	University House
Arts II	Health Centre
SCVA	Sports Centre
Restaurant	Suffolk Walk & Music Centre
Norfolk Terrace	Waveney Terrace
Suffolk Terrace	Orwell/Wolfson Close
	Chaplaincy

b) Proposed installation

It is proposed that the boilerhouse be shut down as early in the summer as possible, say mid May until at least the end of September, possibly to mid October. The principal requirement is to stop using the boilerhouse at times when boilerhouse and distribution efficiencies are at their lowest, at which time the effective cost of heating by heavy oil is greater than by electricity via heat pumps. Another effect of the prolonged shutdown is to enable maintenance work to be carried out over a longer period with less overtime working and less disruption to other maintenance services and also to make boilerhouse staff available for other duties.

To allow this closedown to occur and still allow relatively low grade heat to be available for residences and adequate hot water services to be provided, it is proposed to provide:

i) Heat pumps connected directly to the secondary heating water circuits.

Waveney Terrace I,	200KW
Waveney Terrace II,	200KW
Suffolk Terrace II,	200KW
Norfolk Terrace D,	200KW
Norfolk Terrace F,	100KW
Suffolk Walk,	70KW
Orwell/Wolfson,	100KW

ii) Additional Domestic hot water electric heaters.

Chemistry I	36KW
Science Building	24KW
Biology	36KW
Library	24KW
Computing Centre	9KW
Launderette	36KW
Registry	18KW
Maintenance	9KW

It is anticipated that the use of heat pumps will within the times 7.30 to 8.30am and 5.00 to 11.00pm and would be in use for about 30 days during May and early June and about another 30 days during September and early October. There may be a few days, cold or wet at other times during the summer and it is anticipated that heating via heat pumps would be available for about 75 days per year.

Domestic hot water would be provided for the whole shutdown period, 150 days and electricity consumption could be restricted via time clocks to the period 2.00am to 6.00am (night rate tariff) and an afternoon boost 3.00pm to 4pm.

c) Heat Pump Details

The only British Manufacturer of Heat Pumps of the size proposed is the York Division of Borg-Warner Ltd, Basildon, Essex and it is proposed to use their AWHP range. It is proposed to use two sizes of machine for the duties required:

1) 200KW heating duty, model AWH 65.
2) 100 & 70KW heating duties, model AWH 25.

The larger model has been on the market for about three years. The first installed being two units on the roof of an office block in London, Westminster, which has been used for both cooling and heating duties. They are housed in an acoustic cover which is extremely effective for these noisy machines. The smaller model is more recent and performance details are not so readily available and one cannot be seen running yet.

Some performance figures are given for the AWH 65, to produce a hot water flow temperature of 45^{o}C (113^{o}F).

Ambient air temperature ^{o}C	0	5	10	15
Heating capacity KW	183	227	272	300
Coefficient of Performance	3.01	3.48	2.90	4.08
Electrical loading KW	60.8	65.3	70.0	73.5

The machines are large 3441mm by 2661mm by 2388mm high and have four large air handling fans and are noisy. They will require to be housed in well-designed acoustic houses for the proposed locations.

d) Locations

The hear pumps would be located adjacent to the appropriate heating plantrooms, usually within sixty feet distance, with pipes and cables between. A plan has been prepared marked with these positions. All locations require that particular attention be paid to containing the noise generated by the large compressors and fans in the machines. especially in enclosed locations such as behind Norfolk and Suffolk Terraces.

3. Estimated Costs

At this point, it is possible only to estimate costs for the scheme in an approximate manner. A quotation for the provision of heat pumps has to be obtained from the local agent and this is to be modified slightly. Approximate costs of plumbing and electrical connections have been checked. The approximate costs are given:

a)	Eight heat pumps	125.000	
b)	Acoustic houses		50.000
c)	Installation, Connections		30.000
d)	Other water heaters, HWS	25.000	
e)	Contingency & Fees		20.000
	Total approx costs		250.000

4. Programme

In order to obtain as much operating experience as possible without delay, it is considered that heat pumps should be installed and commissioned before the beginning of Summer, say early in May. The quoted delivery period is almost six months, requiring an order to be placed at the beginning of November. A few weeks are required prior to this in order that design considerations can be finalised, so it is imperative that a decision to proceed should be given at least by early October. Any significant delay should effectively delay the whole operation until the following year, avoiding a situation where heat pumps may be installed just by the end of summer, standing untried until the following spring.

5. Financial Assessment

The project is to be justified by saving resulting from the boilerhouse shutdown together with such staff savings as may be determined.

The saving consist of:

a) Fuel oil savings
less b) Electricity costs
less c) Maintenance costs of additional equipment
plus d) Reduced maintenance cost of boiler and other plant.

a) Fuel Oil

During the period May/September 1981, nearly 520.000 litres of heavy oil were received, at present prices (12.18p per litre) worth &63.200. This quantity is part of an eleven year low for fuel oil consumption, obtained partly due to better insulation but mainly be better operating procedures, frequent attention to reducing the levels of heating everywhere and by continual attention being given to energy conservation. Although other measures may subsequently improve on this figure, it is felt to be a valid starting point for the present consideration.

b) Electricity costs

1) Heat pumps

The total heating load is 1140KW and from two-hourly temperature records kept by the boilerhouse staff, air temperatures during the appropriate times can taken to be an average of 48^{o}F. The C.o.P. of the AWH 65 is 3.8 at this ambient temperature, the C.o.P of the smaller unit is likely to be a little worse and an average C.o.P. of 3.65 has been assumed. From this, an electrical load of 312KW is established.

The period of operation is 7 hours per day, operating season is about 75 days, electricity costs to the University is approx 3p/KWh. An electricity cost of £4914 is arrived at, a slight adjustment to MD may rarely occur, so the approx cost of electricity may be quoted at £5000.

2) Electric HWS heaters.

The total connected load is 700KW, 4 hours per 24 will be during the night at a rate of 1.5p per unit approx, 1 hour per day at 3p per unit, total electricity cost for 150 days is £9,500.

The total electrical running cost of the heat pumps and HWS heaters will be £14,500.

3) Boilerhouse costs.

The boilers have 15Hp fans, there is an oil circulating pump, main site circulating water pump heaters and lighting are all in use almost continuously. It is estimated that the boilerhouse requires an average of 40KW whilst it is in operation and the cost of this, almost £4,500 must be deduced from other electrical costs of the project.

The nett electrical running cost of the project is therefore £10,000 per annum.

c) Maintenance Costs

As part of the assessment of the proposal, a visit has been made to the one location where an AWH installation has been in operation for about a year and the YORK factory at Basildon has been visited where machines were seen to test and manufacture of machines was seen. Operating and maintenance literature has been surveyed and it would appear that little relative cost of maintenance would be involved. An annual cost averaged over the first 10 years for Heat pumps and electric heaters has been estimated at about £6,000 per annum. As in all other Projects considerations, no allowance is made for amortisation of the plant capital cost. A life of 20 years can be put against the equipment.

d) Boilerhouse Maintenance Cost

The boilerhouse is manned for 24 hours per day, there being 4 boilerman and 4 boilermates taking shifts. The gross cost of this for a 5 month period is £32,000.

With the introduction of a 5 month shutdown, there could be a reduction in the number of hours worked by these men. It is for discussion as to how far the reduction can be taken and no figures can be quoted until full consultation is conducted, but to give an idea, if the eight men reverted to a 5 day week, normal working hours, which is possibly the greatest reduction from £32,000 to about £20,000, saving £12,000 per annum. It is likely that actual agreed savings may be some fraction of this figure, possibly half.

The boilerhouse staff would not be idle during the shutdown period. part of the time would fall during the most popular staff holiday period and the remainder of the time could be divided between boilerhouse maintenance and other assistance on plant and equipment, routine maintenance and to some extent enabling outstanding work to be brought up to date.

As a very minimum, it can be said that saving in this direction would completely offset the additional cost of maintaining the new heat pumps and heaters, additional savings being subject to agreement.

Bringing together the four items to be considered for financial assessment of the project, the savings of a-b-c+d amount to about £53,000 per annum.

Conclusion

The expenditure of £1/4 million on any scheme must be considered with caution and it cannot be denied that there is some element of technical risk in the present project. The significant factor about the project is the novelty of using heat pumps and to use them in Summer, or at least into Spring and Autumn. it would obviously be simpler and more effective to simply shut down the boilers and not provide heating at all, just domestic hot water heaters at a quarter of the cost. This would affect Conference Trade, the decision has to be made as to the necessity of heating availability and to date, the answer has been a definite 'yes'.

In the event of the University proceeding with this project, a formal application for a grant towards the cost of heat pumps is to be submitted. The Energy Technology Support Unit is prepared to consider for 25% aid, such schemes as may be used to demonstrate new energy conservation technology applications. Preliminary correspondence suggest interest by this Department of Energy unit. They need about 3 months in which to make a decision and in view of the need to make an early decision within the University, not too much account should be taken of this possiblity of assistance in our decision making.

This application of heat pumps should not be considered very much further, to close the boilerhouse completely for example. the cost of energy via heat pumps is attractive only to a degree, being better than energy from our district heating system in summer, but not in winter. In the former, despite rigid attention on efficiencies and reduction in water flow temperatures the system losses are great in proportion to the heating needed by residences only.

Other alternative methods of heating have been briefly considered, the most attractive being groups of communal heat store units. Such systems cannot be seriously considered, mainly due to the limitations to the electricity supplies.

It having been established that some degree of space heating in residences is required between late May and early October, it is considered that the present project for heat pumps should be promoted.

B. **FINANCIAL APPRAISAL OF THE HEAT PUMPS - by Professor K.N. Bhaskar**

1. Introduction

Normal commercial criterion involves performing a DCF appraisal on the cash flows of the project. The information used in this appraisal involves:

1. The document entitled "University Plain Summertime Heating"

2. Normal financial criteria used by firms in the evaluation of energy related projects.

I have not had sufficient time to elicit all the information required for a full analysis and the conclusions below must be regarded as a first approximation.

2. Summary and conclusion

2.1 On the available evidence and bearing in mind the risky nature of the project, the conclusion to the financial appraisal is that at best, the project is likely to be marginal in financial terms and at worst produce a loss.

2.2 The project is risky since it involves new technology with the cost over-run problems of prototype/newly designed equipment. (Many commercial firms have found similar problems in related projects). The figures provided do not make any allowance for the maintenance of the heat pumps and water heaters. Commercial experience would run counter to this argument. Risk is also exhibited in this uncertainty surrounding the 25% grant from Energy Technology, the labour savings, and an additional £10,000 that may be spent on existing buildings (see 5.2). Moreover the duel savings may not be achieved.

2.3 Given that such a project is risky and would normally be considered risky notwithstanding the points highlighted in 2.2, it would be reasonable to expect such project to earn a minimum real rate of return (as measured in discounted cash flow (DCF) terms) of between 15% and 20%.

2.4 With long term interest rates in the US approaching 20% the UK capital markets will be forced to move closer to the US. The opportunity cost of spending £225,000 will be an interest of £38,000 (if interest can be earned at 17%). This potential income to the University is automatically reflected in the DCF calculations as is depreciation.

2.5 The DCF calculations produce rates of returns as follows:

	Assumption	Main elements	Rate of return (yield/IRR)
(a)	Central	No grant No labour savings All others information as per original estimate	11%
(b)	Pessimistic	As per (a) but fuel savings are not fully achieved and there is a 20% over-run of capital expenditure	-16%
(c)	Optimistic	As per (a) but 25% Energy grant assumed	34%

Note that the terms central, pessimistic and optimistic are simply labels. A case could be made for thinking that the central case is indeed optimistic. In my experience in similar exercises in the private sector management have used a more pessimistic scenario on this type of project as their central case assumption.

2.6 The University will have extremely high demands on any cash over the next few years. Possible uses of spare case include:

(a) academic developments
(b) protection and encouragement of research
(c) buffer funds during the period of adjustment
(d) compensation for loss of office

The principal and interest that can be earned on the proposed capital expenditure is more certain. This coupled with the very high cash demands of the University would necessitate the undertaking of projects only if (a) the return was exceptional and/or (b) the project has a low risk attached to it.

2.7 In essence the project is risky and marginal. Only in the most optimistic case does it make a high rate return (34%). The returns of 11% in the central case is not sufficient to justify the University undertaking a risky project in a period of case shortage.

2.8 These conclusions may be modified if:

(a) The UGC takes into account any reserves in the "adjustment" period and in effect deducts this from the University recurrent grant. In essence this will mean that the University has lost £225,000 whereas the heat pump project may generate some cash contribution in later years.

(b) If the University uses the money to delay the taking of harsh decisions then the money have been better invested in a project which would produce a cash contribution in later years.

The University must be aware of the competing pressure and make a decision based on all the information available.

2.9 If UEA considers that the University ought to spend any surplus cash so that it is not clawed back by the UGC or used to defer difficult decisions, then I believe UEA ought to have a full list of all possible projects both academic and non-academic and accept those that achieve the greatest return (either cost cutting or revenue generating). This should include academically-related projects since £225,000 or so invested in an academic area may produce additional cash flows of much greater than £58,000 especially if the UGC because of this academic development regard UEA in a more favourable light in the future.

If the University, after considering all available projects, decides that this project is the best, then I would support this project even if it did not meet normal commercial criteria.

3. Project life

The life of the project has been assumed as five years. This is the University's current long term planning horizon. Several firms visited by myself this year regarded five years as a maximum for such an energy-related project. (One of the problems in anticipating a longer time horizon in the question of obsolescence and maintenance of technologically advanced equipment).

4. Central assumptions

There are:

(a) The fuel savings hoped to be achieved are actually achieved. I have reperformed the numerical calculations and they show a saving of £54,802.

(b) The capital expenditure is as per scheduled at £225,000. There is not Energy Technology grant.

(c) No labour savings are achieved.

Assumptions (b) and (c) may seem unnecessarily harsh but section 4 discusses the validity of the central assumptions and one of the conclusions of that section is that there are so many unknowns that it is probably not unreasonable and commercially prudent to assume (b) and (c).

The cash flows are as follows:

	1983	1984	1985	1986
Capital expenditure in £	-225,000			
Fuel savings in £	54,802	54,802	54,802	54.802

The DCF calculations are:

	@ 15%	@20%
Net present value in £	-13,740	-28,330.2
Yield/IRR	10.95%	

Conclusion

This project would not normally be considered financially worthwhile.

5. Validity of assumptions

5.1 Fuel savings

(a) It may be argued that the fuel savings over the next five years may be greater than that because of increasing real oil prices. However on balance many energy experts would predict that any increase in the real price of oil over the five year period would be matched by real increases in electricity prices.

(b) A more pessimistic view of the fuel savings could be taken. This would involve:

(i) Heat pumps cost (500KW x 10 hours x 125 days @ .03)
= £18.7?

(ii) Hot water heaters cost (1000KW x 8 hours x 155 days @ .08)
= £22.3?

(iii) Oil saving as per estimate
= £78.08

5.2 Capital expenditure

Many firms currently installing energy - related costs have found a substantial over-run on capital expenditure. There is also some question concerning £10,000 expenditure on the CPC2 building for necessary modifications to the air conditioning system (required by the installation of heat pumps).

5.3 Maintenance costs on heat pumps and hot water.

No allowance has been made for maintenance costs and it is highly likely that over a five year period some maintenance will be involved.

See below.

5.4 Labour savings

The heat pumps and hot water heaters will require some labour to maintain the equipment and buildings. It is likely that any labour savings will be more than compensated by additional maintenance labour and/or parts.

6 Pessimistic scenario

A reasonable pessimistic scenario would comprise:

(a) Over-run on capital expenditure to £270,000
(b) Fuel savings reduced to £37,010 as per section 5.1

No allowance has been made for an Energy Technology grant (which may be countered by the additional money to be spent on CPC2). No labour savings have been allowed. No maintenance costs have been included.

The cash flows are:

	1982	1983	1984	1985	1986
Capital Costs	-270000				
Savings	37010	37010	37010	37010	37010

The DCF calculations are:

	@ 15%	@ 20%
Net present value in £	-127,327	-137,181
Yield/IRR	-15.97%	

The project is clearly not worthwhile.

7 Optimistic scenario

The capital expenditure and fuel savings are taken as per original estimate (i.e. as in section 4). No maintenance is assumed.

(a) Assuming labour savings of £7,500 (1/3 of £22,500) then the DCF calculations show a yield/IRR of 19.5%.

(b) Assuming no labour savings but a 25% Energy Technology grant, then the DCF calculations show a yield/IRR of 34.4%.

(c) Assuming both a 25% Energy Technology grand and labour savings of £7,500, then the DCF calculations show a yield/IRR of 34.4%.

(b) and (c) are clearly worthwhile whilst (a) may be viewed as more marginal. Since labour savings are unlikely to be achieved (or compensated by maintenance costs) (b) is probably the most feasible. Hence (b) was used in 2.5.

C. SUMMERTIME HEATING: HEAT PUMPS

Summary of Conclusions of Paper by Dr. N.K. Tovey

After a detailed analysis of relevant climatic data, and several technical matters relating to the Heat Pump Project, the following conclusions are drawn:

1. The heat pump running costs given in B. Mitchell's document are substantially overestimated. This arises from a 25% overestimated in the number of days the heat pumps will be required, and a significant overestimate on the average daily use. Even a most pessimistic approach gives only 60% of the quoted figure.

2. Likewise, the costs of running the EHWS are overestimates - the maximum likely being about £2000 below that quoted.

3. The boiler house savings are overestimates. At present it is difficult to justify more than 75% of the quoted figure.

4. The project has not considered the marginal costs of heating via oil as opposed to heat pump. The latter are only 50% of the former even more when the main boiler is on and we would be very foolish not to recognise this and thus extend the period of operation of the heat pumps.

5. If we recognise that an extension of the operation of heat pumps is desirable, then it will then become economic to isolate 2 sections of the primary heating main i.e. at the Sports Centre, and at Suffolk Walk during the extended heat pump operation.

6. Several different causes of action have been considered. With each of the costings, there being no fewer than 288 different possible estimates. However, the extreme range is:

Maximum savings	£85520
Minimum savings	£49750

   For the maximum savings the assumptions are:

   Extended heat pump use starting late March finishing early November. Primary main isolated at 2 points indicated above. Boiler shutdown 2 days after improvement in weather in early May and restarted about 1 - 7th October.

Careful control of heat pump use. A diversity factor included in EHWS calculations.

For minimum saving the assumptions are:

no extended heat pump use or primary main isolation. Boiler shutdown $2^{1/2}$ + weeks after weather improvement. Almost no control of heat pump operation. No diversity factor in EHWS calculations.

7. It is desirable that the heat pump be equipped with dual thermostats; on for morning use, the other for evening use. The morning thermostat should be set in the range 18.0 - 18.5^{o}C (approx. 65^{0}).

8. Before proceeding the University should explore the possibility of installing longer heat pumps capable of whole year operation as these are cheaper to run even when the main boiler is on.

9. Provision of HWS be other means should be investigated before a decision on an electric system is made.

10. If the University implement such a heat pump scheme it will obtain considerable publicity as a result of these energy conservation strategies.

Detailed Comments by Dr. N.K. Tovey
on
Document entitled University Plain : Summertime Heating

1. Introduction

Several technical matters arising from the document prepared by B. Mitchell and dated 6th October 1981 are considered in this report. They are grouped under three headings:-

1. An evaluation of climatic data to enable realistic assessments of the heat pump usage to be made.

2. An assessment of the heat pumps to predict their performance in meeting dynamic as opposed to steady state situations.

3. An appraisal of the costs and savings based on data obtained in 1 and 2 above.

The main conclusions for each section are summarized in the general conclusion at the end of this report.

2. Climatic data

2.1 <u>Introduction</u>

The heat requirement of a building is directly proportional to the temperature difference between the inside and outside. To assess the likely demand for heating the daily ambient temperature records kept at the UEA boilerhouse were analysed. Attention centred on the periods May - June for the years 1977 - 81 and September 15-October 15 for the years 1977 - 80. In addition data for the whole of July, August and the early part of September 1977 were obtained.

The raw data is in the form of regular 2 hourly measurements of the external temperature and some 6000 such measurements were scanned in this analysis. As a check on the validity of the periods chosen the 'degree-days' for each month were compared with the averages over the period 1957 76.

The following conclusions were draw:-

1) The average May for the selected period (i.e. 1977 - 81) was 6% colder than average.

2) The average June for the same period was 10% colder than average.

3) The average September was 3% warmer than average (although it should be noted here that the degree days relate to the whole month and not the last 15 days used here).

4) For the month of May the years 1977, 1978 and 1979 were all much colder than average (15% for 1977).

5) For the month of June, 1977 was over 50% colder than average, and was the coldest June since 1957.

6) October 1977 was significantly warmer than average (20%) while October 1980 was significantly colder (once again 20%).

7) July, August and September 1977 differed from average months by no more than 3% in each case. The global 'degree-days' for the three months was exactly the same as the corresponding aggregate in an average year.

2.2 Analysis of Data

The 12 temperature reading were average to produce a daily mean. In addition the mean temperature in the period 0700-1700 on working days was evaluated when it was clear this fell below 58^{o}F. The data is presented in Tables 1-6 in the Appendix and each table covers one of the following periods:-

(i) 1st - 15th May
(ii) 16th - 31st May
(iii) 1st June - shutdown
(iv) 1st July - 15th September
(v) 15th - 30th September
(vi) 1st - 15th October

These tables show the Temperature distribution in 2^{o}F classes. All classes above 60^{o}F (15.6^{o}C) are lumped together as at this temperature, incidental gains from body heat, appliances, lighting etc. are sufficient to produce an acceptable internal temperature.

Between 58^{o} and 60^{o}, incidental gains will frequently be sufficient to avoid the use of direct heating in residences.

In working buildings, an external temperature of 58^{o}F will give rise to at least 63^{o}F will give rise to at least 63^{o}F (external temperature of 60^{o}F will give approximately the maximum legal permitted temperature in most of our buildings).

To cover the possibility of heating requirements to the teaching wall and other administrative areas during the shutdown, Tables 7 - 11 relating only to working days were complied. To allow for cold mornings and capacitance effects, the averaging period was extended to include 07.00-09.00 in addition to the working day.

2.3 Conclusions from the temperature data

(i) No heating is necessary July 1st - 15th September in working areas, the one slightly cool easily be accounted for by the substantial thermal capacity of the buildings.

(ii) Heating may be required occasionally in residences in the late evening during the period July 1st - 15th September.

(iii) In June there is no definite heating requirement in working areas although possible/probable on one day in June. However, most of these days occurred in 1977 which was 50% colder than normal and the main boiler would have been on anyway.

(iv) Similarly in late September, 80% of days do not require heating with no definite requirements.

(v) The average May day in the period analysed was 9% colder than average but it is clear that there is no scope for shutting down the boiler much before 15th May. In 1981 it could have been shut down about 7/8th May.

(vi) In 1979 it was certainly possible to have had no boiler operational until 15th October but in other years, a start up close to 1st October would have been necessary. In 1978, there was a two week mild spell during which the boiler could have been turned off again.

(vii) During the period 15th May - 1st October the total number of days with possible heating requirements in teaching areas were as follows:-

1977	1978	1979	1980	1981 (to Sept 15th)
22	19	10	8	1 (no data available yet for last 15 days)

(viii) An operating schedule has been produced for the above period during the relevant years assuming that the heat pump had already been installed (See Figs. 1 and 2).

1977	Boiler off on June 9th with a possible short term shut down in late May
1978	Boiler shut down 25th May
1979	Boiler shut down 13th May
1980	Boiler shut down 13th May
1981	Boiler shut down 7the May

(ix) If this strategy had been adopted, then the number of possible heating requirements in teaching/administrative areas are as follows:-

1977	1978	1979	1980	1981
8	8	4	8	1

(x) Capacitance effects are sufficient to permit no heating on slightly cool days provided they are not grouped continuously. Capacitance effects are certainly sufficient to cope with a single day, and are probably sufficient for two days. Removing such days from the analysis leaves:-

1977	1978	1979	1980	1981
0	0	0	5	0

Where there are two consecutive cooler days the second of these has been indicated by + on the chart. There is, on average, 1 such period a year.

(xi) The 5 days in 1980 formed a continuous group in May (20-25). The temperature was sufficient to provide heating to the standard required by the Office, Shops and Railway Premises Act 1963, but it must be assumed that had no general heating been provided during this period some supplementary heating would probably have been in use by secretaries.

2.4 Operating Strategies for the Boiler and Heat Pump

The temperature normally shows a marked improvement in early/mid May, and thereafter considerations for shutting the boiler down can be made. The charts in Fig. 1 and 2 show the boiler in operation about 2 days after the improvement and thus represent optimistic shut down dates.

It is suggested that in a more realistic schedule, the boiler should be kept on for seven days after the improvement in the weather supplying heat as required. Thereafter the residences should be switched over to the heat pumps, for providing heat in the evenings. The teaching buildings should remain 'on' and in one year in five it is possible that short term boiler operations (~ a few days) may be necessary up to June 10th but during this time heat pumps can supply the needs in residences.

At the end of September, the boiler should be ready for start up by October 1st, although this may be delayed up to two weeks. No substantial maintenance should thus be done on the boilers before about 15th June or after 15th September.

2.5 Boiler and Heat Pump Use

The distribution between boiler use and heat pump use in the periods 1st May - 24th June and 15th September - 15th October are shown in Figs. 1 and 2. The hatched areas represent possible heat pump use during the period.

(i) The average number of 'boilerless' days is 140 but the optimum.

(ii) A realistic schedule suggested in 2.4 above would reduce the average to 130 days.

(iii) A pessimistic schedule would reduce the number further to 120 days.

20 days use up to the end of June
26 days use up to 15th September and
12 days after 15th September
i.e. a total of 58 days.

(iv) However, these figures relate to the optimum 'boilerless' strategy in 2.5 (i).

For the realistic schedule in 2.4, the corresponding figures would be:-

16 days to end of June

26 days in July, August and early September
10 days after 15th September

giving a total of 52 days.

(v) Using the pessimistic scenario and assuming extra boiler use is at both ends of period gives for the same figures:-

14 days to end of June

26 days in July, August and early September

8 days after 15th September

giving a total of 48 days use.

2.6 Implications for costs and savings

1. A period of 150 days is too long for a realistic shut down in an average year.

2. This figure should be reduced to about 130.

3. Under all these scenarios, the heat pump usage for auxiliary heating is significantly less than assumed in the document on summer time heating.

4. A summary of the three scenarios is given in the following table.

	Optimum Scenario	Realistic Scenario	Pessimistic Scenario
boilerless days	138	130	120
heat pump use	58	52	48

The optimum scenario requires short term operation of the boiler on one or two years in five. The other two scenarios do not make this assumption and assume continuous boiler use until shut down.

3. Assessment of Technical Aspect of Heat Pumps

3.1 Introduction

To assess the likely performance of the heat pumps, one of the residences has been selected for a detailed study namely Waveney Terrace.

A heat loss rate of 56KW^{o}C^{-1} has been assumed being the mean value I believe agrees closely with that used by B. Mitchell.

A thermal capacity of 6GJ^{o}C^{-1} has been assumed - this being the mean of two separate assessments. It is possible that this figure may be in error and an assessment of the effects of changing the value from 3GJ^{o}C^{-1} to 9GJ^{o}C^{-1} was done. Though the actual temperatures varied in response, the overall energy consumption was no more than 10% different and thus the calculations are fairly insensitive to substantial changes in thermal capacity.

An occupancy of 500 persons (c.f. 750 rooms) for the hours 20.00 - 08.00 is assumed and 200 at other times.

An average of 80W person consumption in appliance is assumed and allowances are made for incidental gains from hot water and cooking.

Solar gain data for a cloudy day in June has been assumed - i.e. diffuse gain which should be the same for both sides of building.

3.2 Sizing of Radiators

The heat pump delivers water at 45^{o}C which is 20^{o}C colder than the normal operating temperature of the radiators. Consequently less heat will be radiated from them.

For radiative heat transfer the heat flow is proportional to $T^4_{rad} - T^4_{air}$.

Substituting the relevant values gives a heat transfer rate which is about 51% of normal.

Heat transfer from radiators in only partly via radiative means and using an alternative approach assuming equivalent conductive values give a figure of 57%.

For convenience the mean value of about 54% is assumed.

The heating will have been designed for -1^{o}C external conditions (i.e. 16.5^{o}C temperature difference from the balance temperature). This gives a maximum heat load of 924KW. Normally radiators are over-sized by up 20% to allow for dynamic effects, i.e. the maximum heat output under normal conditions would be approx. 1M.

Thus we can expect the radiators to handle up to 540KW when connected to the heat pump. This figure is precisely that of the output of the heat pump at 10^{o}C and thus provides a satisfactory match to our existing system.

If the heat pump were operating at say 13^{o}C when the combined output of the two Waveney Heat pumps is 600KW, the temperature of the circulating water would probably rise thereby reducing the COP slightly. Conversely for temperatures less than 10^{o}C, the radiator temperature is likely to be a little lower creating an <u>increase</u> in the COP.

For subsequent design purposes it would seem sufficient to use the quoted figures.

3.3 Assessment of likely use of Heat Pumps

The days on which heat pumps are likely to be required are shown in Figs. 1 and ??. This must be regarded as somewhat pessimistic as almost certainly no heating will be required for isolated days and probably not for two consecutive days either. However, in this analysis it is assumed that these are 'heating days.

Five days were selected within the periods studied.

These were 17th June 1981 when the mean temperature was 57^{o}, 25th June 1981 (54.6^{o}), and a series of three consecutive days 29th September - 1st October 198?, which was the coldest spell in all five years studied. In fact even the optimum strategy suggests that the baler would have been on to cover this period.

A thermostat setting of 19.5^{o}C was initially assumed with heating possible between 17.00 and 23.00, and a single 1 hour in the morning. For the 'cooler' days the 1 hour is probably inadequate, and a possible 2 hour heating period 07.00 - 09.00 was assumed. Realistic incidental gains were assumed as was the diffuse solar gain obtained on a dull day even through it is clear some of the days had direct solar gain.

Note: The current maximum legal setting of thermostats is 19.0^{o}C although residences as excluded from this regulation, the intention has been that this should be universally applied throughout the University. In the subsequent analysis a figure of 19.5^{o}C (upper limit - 19.0 lower limit) has been assumed. This will tend to overestimate consumption over that which would have occurred had 19.0^{o}C been used.

In some of the analyses a morning thermostat at 18.5^{o}C is assumed. This undoubtedly would permit better control and the lower setting can be justified as people's activity level is usually significantly higher at that time, and also the incidental (particularly diffuse solar) gains will normally cause the temperature to continue to rise about this temperature.

(i) June 17th 1981

a) The temperature fell to a minimum of 18.3^{o}C (65^{o}F) overnight, the two hour heating brought the temperature up to 19.0^{o}C by mid afternoon and no heating was necessary in the evening, see Fig. 3(a).

b) Had only one hour heating been provided, the temperature would have risen to 18.6^{o}C by 08.00, but incidental gains would have kept the internal temperature in the evening about the thermostat setting.

c) If no heating had been provided in the morning, the temperature would have fallen to 18.2^{o}C thereafter incidental gains would have increased the temperature, and only in the late evening would heating have been required.

The costs for heating Waveney for that day would have been £8.50, £4.30 and £1.00 respectively.

(ii) June 25th 1981

The analysis is summarised in Appendix 1, 2 hours morning heating necessary, cost £15.30, (with morning thermostat at 18.5^{o}C £14).

(iii) 29th September - 1st October

Two hour heating in the morning is definitely required during this period. the mean temperatures on the three days were 53.0^{o}F, 48.8^{o}F. if only 2 hours morning and 6 hours evening heating were available, it would not be possible to raise the temperature in the evening above 19.2^{o}C. Alternative strategies might include the manual over-ride of time switch to give the possibility of continuous heating on these days controlled by thermostat only. Some economy could be achieved if the thermostat was set at 18.5^{o}C for the morning period. The minimum and maximum likely daily costs for heating Waveney for the three day period are £90 and £96 respectively.

The calculations used in the above assumed dull solar gain conditions and a thermal capacity of 6 GJ. It is this last factor which reduces the demand in cases tested below, from that predicted from simple mean temperature conditions, we were careful in the use of the heat pumps the actual demand would be about 50% of that predicted from simple mean temperature conditions. Even the most pessimistic value is only 70%. Thus the values obtained from mean temperature data must be regarded as being the maximum possible demand.

Costs for running the heat pump range from £2770 for the maximum possible cost with the optimum distribution between boiler and heat pump use and £1045 for careful management of heat pump use with the pessimistic distribution. The full details are given in Appendix 1.

3.4 The COP's of the heat pumps

From the data quoted, the isentropic efficiency is 41% - 43% for all external conditions. We can assess the likely values of COP with different high temperature conditions. For instance if we were aiming to provide water at 65^{o}C and not 45^{o}C we should expect lower COPs.

	O^{o}C	5^{o}	10^{o}C	13^{o}C
isentropic efficiency	42.6	43.8	42.9	41.1
45^{o}	3.01	3.48	3.90	4.08
47.5^{o}	2.70	3.02	3.42	3.72
65^{o}	2.08	2.25	2.46	2.60

(The figures for 47.5^{o} and 65^{o}C assume an isentropic efficiency of 40%)

Normal heating systems operate with about 10^{o}C between flow and return temperatures. As we are expecting only 50% heat output during the period of operation a 5^{o}C temperature difference is likely. Thus we may have to expect a top temperature of 47.5^{o}C with a consequent increase of about 10% in the electricity consumed.

3.5 Auxiliary Electric Hot Water Services

It is proposed to instal an extra 192KW of electric hot water heating in addition to the 508KW? (700 -192KW) at present in residences etc. I understand that the five hour suggested period is based on actual existing information relating to Waveney Terrace (verbal communication from B. Mitchell).

Of the total installed capacity of 700KW, 496KW would be in areas needing it 7 days a week in summer. This figure is derived as follows:- 508 existing less Arts I less Arts II + Laundrette.

In assessing the use of heaters for hot water we should allow for only 5 days use in teaching/administration areas. Further the resulting figures will provide more than adequate water (e.g. over 500 galls in ENV/MAP).

Further we should allow for the fact that at present we use the existing heaters for two weeks a year.

Finally we may wish to consider a more realistic strategy for the residences in the vacation - i.e. a 60% load factor at this time, 100% during the rest of the time.

The calculations are as follows:

(i) existing use 508 x 14 days x 5 hours = 35560 kWh

(ii) teaching/admin. use at 5 days a week

strategy	optimum	realistic	pessimistic
days use	100	93	86
	102000 kWh	94860 kWh	87720 kWh

(iii) other buildings

	strategy	optimum	realistic	pessimistic
	days use	140	130	120
a)	no diversity	347200 kWh	322400 kWh	297600
b)	with diversity	267840 kWh	252960 kWh	238080

The total extra use in electricity is thus assessed as

strategy	optimum	realistic	pessimistic
no diversity	413640	381700	349760
with diversity	334280	312260	290240

3.6 Savings in Boilerhouse Electricity

The document 'SUMERTIME HEATING' is approximate in its assessment of boilerhouse use of electricity. It mentions 15 hp fans but it is not clear how many there are for each boiler since we can only consider that one boiler is in operation during the relevant period. However, assuming that 40kW is reliable, the savings estimated in that document must be over estimated as they do not account for the fact the for 7 hours, the cost would be at the night time rate. Redoing the calculations using 40 kW for the relevant periods gives

strategy	optimum	realistic	pessimistic
days	140	130	120
energy use	134400	124800	115200
savings	£3445	£3200	£2955

3.7 Marginal Costs of Heating Residences

Although consideration has been given to use of heat pumps during the 'boiler-less' period a check must also be made whether or not the marginal costs for heating the residences when the boiler is on one greater or less than using a heat pump.

For ease of comparison the figures are calculated with respect to the mean temperatures and these represent the maximum possible in both cases. In actual practice the costs of heating directly and by heat pump will be less but in the same proportion.

The figures for oil assume efficiencies of about 85% below 5^{o}C falling to 75% above 13^{o}C. A calorific value in the range 38 - 43 MJ/litre is used.

The data is plotted in Fig. 5 and clearly shows that at all temperatures down to that for which the proposed heat pumps can supply all the heating (i.e. 7^{o}C) oil is twice as expensive as using the heat pump.

We would be foolish not to recognise this fact since from April 1st we could switch over to heat pumps in the residences but retain boiler heating in the rest of the University.

Indeed we should actively consider switching over to heat pump use in residences from the start of the Easter Vacation but continue running the boiler until May defined in the three strategies. The boiler would be brought on again at about October 31st and possibly November 10th/15th.

The <u>direct</u> savings here are estimated at £14000 or a minimum £6300.

In addition to the direct savings, there would be no need for the boiler to operate after about 10.00 and it could be placed on stand-by until about 06.00 the next morning. Whilst it is true that a somewhat similar strategy could be adopted at present, the period could be extended firstly because the residences will be self-sufficient in late evening, and secondly the peak demand the next morning will be much lower. We could expect £2500 saving by this means. If the Library and University House had auxiliary heating then the shut-down to stand-by could be much earlier each evening.

A similar analysis was done to examine the situation for continuation of the hot water supply by auxiliary means. Here the marginal costs are such that only if all the water was heating at off-peak rates with no afternoon boost would it be advantageous to extend the auxiliary heating season.

Under the proposal, the cost for supplying hot water to Waveney would be

Electricity £9 per day (4 hours off-peak 1 hour peak)
Oil £8.40 per day

However, the heat loss from the main flow and return lines alone from the Sports Centre to Orwell Close would amount to £15 - £20 day, and taking these into account it clearly becomes attractive to isolate that section of the pipe line. Similarly, the Suffolk Walk/Suffolk Terrace sections could be isolated.

The overall savings as a result of this alternative strategy amount to about £20,000.

It must be pointed out that even at temperatures colder than 7^{o}C the heat pump operation would represent savings, and except on the very coldest days of winter the most cost effective strategy would be to run the heat pumps for most of the year. However the sizing of the pumps in the proposal are less than half that which would be required for all the year heating. Before committing ourselves to a particular size of pump it might be prudent to examine installation of larger pumps -for instance if capacity were sufficient we could expect an extra saving of £6,200 per annum for Waveney Terrace or £17,670 overall.

3.8 <u>The Teaching/Administration Areas</u>

It is clear from the above that if we installed heat pumps for each building we would save significant quantities of money. However, this is not considered here as it raises several other fundamental questions. However, alternative strategies to electric heating might be considered:-

(i) the use of small gas boilers in all teaching area to provide hot water. The capital cost of this is likely to be greater than electric heaters but the running costs would be less. Further at least one firm to my knowledge has negotiated a favourable rate for gas because they take a higher quantity of gas in summer. We may be able to obtain similar concessions e.g. it helps the Gas Board to balance their supplies between summer and winter.

(ii) In some Science buildings considerable quantities of waste heat are ejected to the atmosphere. For instance, the ENV cold rooms have refrigerators (heat pumps) and the exhaust from these could be used as the cold source for a small water to water heat pump for providing hot water instead of immersion heaters. The same is true for the other science buildings (see document written by myself dated 2.12.75).

These two comments do not affect the implementation of the general scheme but must be considered when examining the additional auxiliary HWS.

4. Assessment of the Economic Aspect

4.1 Introduction

Some of the economic aspects of particular strategies have been discussed already. in this section the global effect on costs is studied. In addition, several comments on the paper by Professor Bhaskar are made.

4.2 Oil savings

The document of B. Mitchell suggests a saving of £63,200 per annum. Using statistics for the past 5 years predictions of soil savings for the three strategies are:

	optimum strategy	realistic strategy	pessimistic strategy
litres	575595	511940	455340
savings	£70,100	£62,350	£55,460

Note (i) These savings do not include any obtained by extended use of the heat pumps.

(ii) Although these figures are to some extent based on the mean for 5 years, and that it can be argued that existing conservation measures in operations may have reduced these figures slightly, the figure used by B. Mitchell refers only to 1981, which was warmer than average and underestimates the saving over the period. In any case, the central scenario projects a slightly lower value than his projection.

4.3 Savings in boiler house electricity

The savings quoted by B. Mitchell are optimistic - see 3.6 and the following are more realistic unless further information is forthcoming:

strategy	optimum	realistic	pessimistic
saving	£3445	£3200	£2955

4.4 Auxiliary EHWS costs

The extra electricity consumed in these heaters is estimated in 3.5. The savings calculated from these figures are:

strategy	optimum	realistic	pessimistic
no diversity factor:	£7446	£6871	£6296
with diversity factor:	£6017	£5621	£5224

4.5 Costs of running heat pumps

The costs for running the heat pumps are as follows:

Strategy	optimum	realistic	pessimistic
maximum possible	£2770	£2500	£2130
poor control)	£1884	£1700	£1448
reasonable control)	£1607	£1450	£1235
careful control)	£1357	£1225	£1044

The control regimes relate to how carefully the use of the heat pumps is controlled. To allow for possible mismatch between heat pump and heating system, these costs should be inflated by 11%. This represents a flow temperature of 47.5^{o}C and a return of 42.5^{o}C. i.e.:

	strategy	optimum	realistic	pessimistic
	maximum possible	£3075	£2775	£2364
	(poor control ((69% of max. possible)	£2091	£1887	£1607
likely costs	(reasonable control ((58% of max. possible)	£1784	£1610	£1371
	(careful control ((49% of max. possible)	£1506	£1360	£1159

4.6 Overall savings without extended heat pump use

The overall savings are as follows:

strategy:	optimum	realistic	pessimistic
savings	£73545	£65550	£58415
costs: max.	£10521	£9646	£8660
min.	£7523	£6981	£6383

SAVINGS :

MIN	£63020	£55900	£49750
MAX	£66020	£58570	£52030

4.7 Overall savings with extended heat pump use

The savings from extending use of heat pumps to cover period 20th March - 7th November would increase savings by about £6300 minimum to £14000 maximum possible depending on the exact length of the period chosen.

Increased savings from increased standby as opposed to operating for boiler with above strategy - £2,500.

Increased savings id main pipes are isolated beyond Sport Centre and Suffolk Walk - £3,000.

Overall additional saving ranges from £6,300 to £19,500.

4.8 Other savings

As a result of the increased shutdown period maintenance will be improved, and we might expect an overall ½% improvement and optimistically a 1%. In a pessimistic scenario we should assume no change. At a cost of about £500,000 for fuel oil, deduct the savings outlined above and figures of £2000 (for ½%) or £4000 (for 1%) are obtained. These could be included in the respective scenarios but I have chosen not to do so at this stage merely to point out a qualitative 'plus' for the scheme. In a similar way, we can expect a significant improvement in the life of the boilers not only from the decreased use, but also by removing the extended periods of low use operation. A 50% increased life expectancy of our boilers might not be unreasonable.

4.9 Future oil costs

All the calculations have been done using present day prices. It is generally accepted that oil prices will rise in real terms and this will increase the value of the savings. Professor Bhaskar argues that it is prudent to neglect this advantage. While this might be so in a pessimistic scenario, it ought not to be for the realistic or optimistic scenarios. The reasons for this are fourfold:

1. Only 12% of electricity is generated from oil.
2. Continued improvements in the thermal efficiency of the power stations mean that less fuel is used. This trend will continue at least for the next 5 years.
3. With continued increases in the size of power stations the labour costs per unit have decreased.

4. The historic trend clearly demonstrates the fact as indicated below:

(Indices 1976 = 100)

	Retail price index	Cost of Heavy Oil to Power Stations	Cost of Electricity to Large Consumers	Cost of Heavy Oil
1971	50	27	44	32
1976	100	100	100	100
1980	174	207	161	209
Compound Increase 1971 - 1980	3%	23%	14%	21%
Compound Increase 1976 - 1980	12%	16%	10%	16%

----- whereas electricity increases have been comparable with inflation, oil prices have gone up 4% - 9% in real terms. A realistic scenario could thus incorporate a 2% real increase and an optimistic one a 4% increase.

4.10 Comments on document by Professor Bhaskar

(i) It is assumed that the project life is 5 years and this is based on industrial experience. This is an unrealistic comparison. I myself have had contact with energy managers at some major industrial firms. Two reasons emerge for the maximum of five years. Firstly, many schemes are related to processes etc. which have limited life spans - say, 10 years maximum and secondly, there are usually energy conservation schemes which can be implemented which have much shorter pay back times. A life time longer than five years would not be unrealistic in our case.

(ii) Comment relating to assumptions over oil prices has already been made in Section 4.9.

(iii) The figures used in the pessimistic scenario are totally unreasonable:

(a) Heat pump running costs:

- these assume 10 hours a day running for 5 days in 6
- such an extended run will only occur on days as cold as 50^oF of which on average there is only one per season
- secondly, it assumes a COP of only 2.28. Even the most pessimistic approach would give a COP of 3 for the temperature range considered
- as shown above, even B. Mitchell's estimate is very much on the pessimistic side and his figure of £5000 should thus be regarded as the most extreme figure.

(b) The EHWS costs reflect 300 KW over the maximum installed capacity. Even if the other figures are accepted, which is questionable, the estimated figure is 42% too high.

(i) Professor Bhaskar raises the possibility of cost over-run. This is certainly a possibility and it would be desirable to have more detailed costings particularly of the acoustic covers.

5. Conclusions

The following conclusions about the project can be drawn:

1. The assumption of a 5-month (150 day boiler shutdown) is over-optimistic.
2. An optimum shutdown period would last, on average, 140 days, but this would require shutting the boiler down within 2-3 days of the improvement in weather in May. Further, it may be necessary to use the boiler for a further short period in late May or June on one year in three.
3. A more realistic strategy would allow 7 days of good weather before shutdown. This would, in general, eliminate bringing the boiler back on again. The shutdown period would be reduced to 130 days.
4. A pessimistic strategy would allow a further 10 days of boiler operation before shutdown reducing the 'boilerless' period to 120 days.
5. Even in the optimistic shutdown period, the use of heat pumps is over-estimated in the report by B. Mitchell. Figures for the three strategies based on average climatic data for the past 5 years are 57, 51 and 45 days respectively.
6. Detailed analysis of selected days shows that the figure of £5000 for heat pump operation grossly overestimates the likely cost.
7. Re-computation of EHWS costs shows a saving of about £2000 when allowance for only 5 day use in administrative/teaching areas is made. Further savings are apparent if a diversity factor is included.
8. The savings in boilerhouse electricity overestimates the potential savings by up to 50%.
9. The report makes no mention of the extended use of heat pumps i.e. use in April and early November even when main boiler is on. The marginal costs for heating the residences are very much in favour of the heat pumps.
10. Alternative means of providing HWS in the teaching/administrative buildings should be carefully examined before adopting an electrical method.
11. The possibility of installing larger heat pumps which could be capable of use in the winter should be explored. The marginal costs favour heat pumps over the present scheme except on the most extreme cold days.

N.K. TOVEY
19th October 1981.

Evaluation of Probable Heat Pump Costs

Mean Temp 57^{o}C, see Fig. 3	
1st scenario, 2 hours heating in morning thermostat (19.5)	£8.40
2nd scenario, 1 hour " " " "	£4.20
(also equivalent to 2 hours with thermostat at 18.5)	
No morning heating (minimum temperature 18.2)	£1.00

Mean Temp 54.6^{o}C	
2 hours morning heating + thermostat at 19.5	£15.30
if morning thermostat were set at 18.5	£14.50
(minimum temperature for both scenarios 18.0)	

Mean Temp 53^{o}C day 1 of Fig. 4	
2 hours morning heating needed, with or without 18.5^{o}C setting (minimum overnight temp 18.0)	£22.00
Heating during most hours in evening, but not full amount.	

Mean Temp 48.8^{o}C day 2 of Fig. 4	
i) 2 hours morning heating + full on in evening	£34.00
ii) continuously on but controlled by 19.5^{o}	£44.00
iii)continuously on but 18.5^{o}C thermostat until mid-day	£42.20

Note: scenario (i) does not permit 19.5^{o}C to be reached in evening thereby affecting next day.

Mean temp 50.5^{o}C day 3 of Fig. 4	
i) previous day as scenario (i) above then similar operation	£34.00
ii) following scenario (ii) above	£30.00
iii)following scenario (iii) above with continuous heating controlled by 18.5^{o}C thermostat in morning	£32.00

Note: if scenario (i) on day 2 is adopted, the minimum temperature overnight is 16.62^{o}C = 62^{o}F.

Tables associated with paper appear on next page.

Table 1

Daily Mean Temperatures for the Period 1st - 15th May
at UEA Boiler House

^{o}F	1977	1978	1979	1980	1981	Total
>44	1	-		-	-	6
44-46	3	-	5	-	1	4
46-48	2	-	0	4	1	9
48-50	4	3	2	3	0	12
50-52	2	6	2	1	0	9
52-54	1	4	0	2	0	8
54-56	1	0	1	0	0	2
56-58	-	1	1	1	1	3
58-60	-	1	0	1	2	4
>60	-	-	0	3	7	14
			4			
	14	15	15	15	12	71

Table 2

As Table 1 for period 16th - 31st May

^{o}F	1977	1978	1979	1980	1981	Total
<50	2	-	-	-	-	2
50-52	1	2	2	1	-	6
52-54	7	5	3	4	1	20
54-56	2	2	3	1	1	9
56-58	2	2	3	2	6	15
58-60	1	1	1	6	2	11
>60	1	4	4	2	6	17
	16	16	16	16	16	80

Table 4

Mean Temperatures for Period 27th June - 14th September 1977

^{o}F	Number of Days
56 - 58	11
58 - 60	11
> 60	55
Total	77

Table 5

Mean Temperatures for 15th - 30th September

^{o}F	1977	1978	1979	1980	Total
50-52	-	-	2	-	2
52-54	2	2	1	-	5
54-56	4	2	2	-	8
56-58	3	4	5	3	15
58-60	2	0	1	4	7
>60	5	8	5	9	27
	16	16	16	16	64

Table 6

Mean Temperatures for 1st - 15th October

^{o}F	1977	1978	1979	1980	Total
>46	-	-	-	1	1
46-48	1	-	-	4	5
48-50	0	-	-	2	2
50-52	2	1	-	3	6
52-54	4	2	-	2	8
54-56	7	2	2	3	14
56-58	0	2	1	-	3
58-60	1	4	3	-	8
>60	0	4	9	-	13
	15	15	15	15	60

<u>Table 7</u>

Temperature Data for Working Periods Only 1st - 15th May

^oF	1977	1978	1979	1980	1981	Total
<44	-	-	1	-	-	1
44-46	-	-	3	-	-	3
46-48	1	-	1	-	-	2
48-50	2	-	0	1	1	4
52-54	4	-	1	4	1	10
54-56	0	2	2	1	0	5
56-58	2	3	0	1	0	6
>58	0	2	1	0	0	3
	1	4	2	4	8	19
	10	11	11	11	10	53

<u>Table 8</u>

As Table 7 for Period 16th - 31st May

^oF	1977	1978	1979	1980	1981	Total
<50	-	-	-	-	-	-
50-52	-	-	-	-	-	-
52-54	1	2	1	-	-	4
54-56	2	3	5	4	-	14
56-58	5	2	1	0	-	8
>58	4	5	5	7	10	31
	12	12	12	11	10	57

<u>Table 9</u>

As Table 8 for Period 1st - 26th June (approx)

^oF	1977	1978	1979	1980	1981	Total
<50	1	-	-	-	-	1
50-52	-	-	-	-	-	0
52-54	-	-	1	-	-	1
54-56	5	1	1	4	1	12
56-58	4	1	0	0	0	5
>58	8	15	19	16	19	77
	18	17	21	20	20	96

<u>Table 10</u>

As Table 7 for Period 15th - 30th September

^oF	1977	1978	1979	1980	Total
<54	-	-	-	-	-
54-56	1	2	1	-	4
56-58	3	1	1	-	5
>58	7	8	8	12	35
	11	11	10	12	44

<u>Table 11</u>

As Table 7 for Period 1st - 15th October

^oF	1977	1978	1979	1980	Total
<48	-	-	-	1	1
48-50	-	-	-	2	2
50-52	1	-	-	2	3
52-54	2	1	-	2	5
54-56	1	1	-	2	4
56-58	3	1	1	2	7
>58	3	7	10	0	20
	10	10	11	11	42

Table 12: <u>Analysis of Temperature Data 15 May - 15 October</u>

(i) 15/5 - end of June mean of years 1977-81
(ii) July-15/9 year 1977 which is typical
(iii) 15/9-15/10 average of years 1977-80

	Number of Days in Each Class in 'boilerless' period			
Temperature	Total Period	Operating Strategy (Figs 1&2)	Realistic Strategy	Pessimistic Strategy
<50^{o}F Heating	2.5	0	0	0
50-52^{o}F "	3.3	0.7	0.7	0.7
52-54^{o}F "	9.8	4.9	4.5	3.5
54-56^{o}F "	9.5	5.3	4.9	3.5
56-58^{o}F Probable Heating	22.6	22.6	19.9	18.0
58-60^{o}F Possible Heating	23.1	23.3	20.9	19.3
>60^{o}F No Heating	81.3	82.9	79.3	75.5
[incidental gains ~7-8^{o}C]				
Total Heating Days (including possible and probable)	70.8	56.8	50.9	45.00
Mean Temperature on Heating Days only	56.27	57.21	57.19	57.30
Approximate cost for supplying heat to all buildings equipped with heating	£4610	£2770*	£2500*	£2130*
Savings in Oil		£70,100	£62,350	£55,460
Nett Saving		£67,300*	£59,850*	£53,330*

* Note: these figures assume maximum possible costs. Probable costs are likely to be significantly less, see Section 4.

LATE APPENDIX TO COMMENTS BY DR N.K. TOVEY

ECONOMIC ASPECTS

The Net Present Values for the project using broadly the three scenarios given in the main paper are given below with the following additional assumptions.

1. optimistic: - real increase in oil of 4%
   £40,000 ETS grant
   saving as per report £85,520

2. realistic: - no ET grant
   real increase in oil of 2%
   saving of £68,470

3. pessimistic: - no ET grant
   no real increase in oil
   cost overrun on acoustic covers and services by
   £20,000 to give total £270,000

The present day values are:

	Life/Discount Rate	10%	15%	20%
optimistic	5yr	+£171,856	+£140,841	+£112,255
	10yr	+£457,201	+£349,048	+£266,906
realistic	5yr	+£45,251	+£22,132	+£2,659
	10yr	+£246,194	+£169,834	+£113,098
pessimistic A	5yr	-£62,549	-£78,215	-£91,461
	10yr	+£66,261	+£18,131	-£19,710
pessimistic B	5yr	-£36,279	-£53,928	-£68,852
	10yr	+£108,843	+£53,494	+£11,985

Note: scenario Pessimistic B assumes some external heat pump operation which is probable.

Approximate values for the internal rate of return are:-

optimistic	5yr	+60.6%
	10yr	+70.3%
realistic	5yr	+20.7%
	10yr	+37.4%
pessimistic A	5yr	-4.0%
	10yr	+17.4%
pessimistic B	5yr	+2.0%
	10yr	+21.9%

Note: most works in public sector assume a 10% discount rate.