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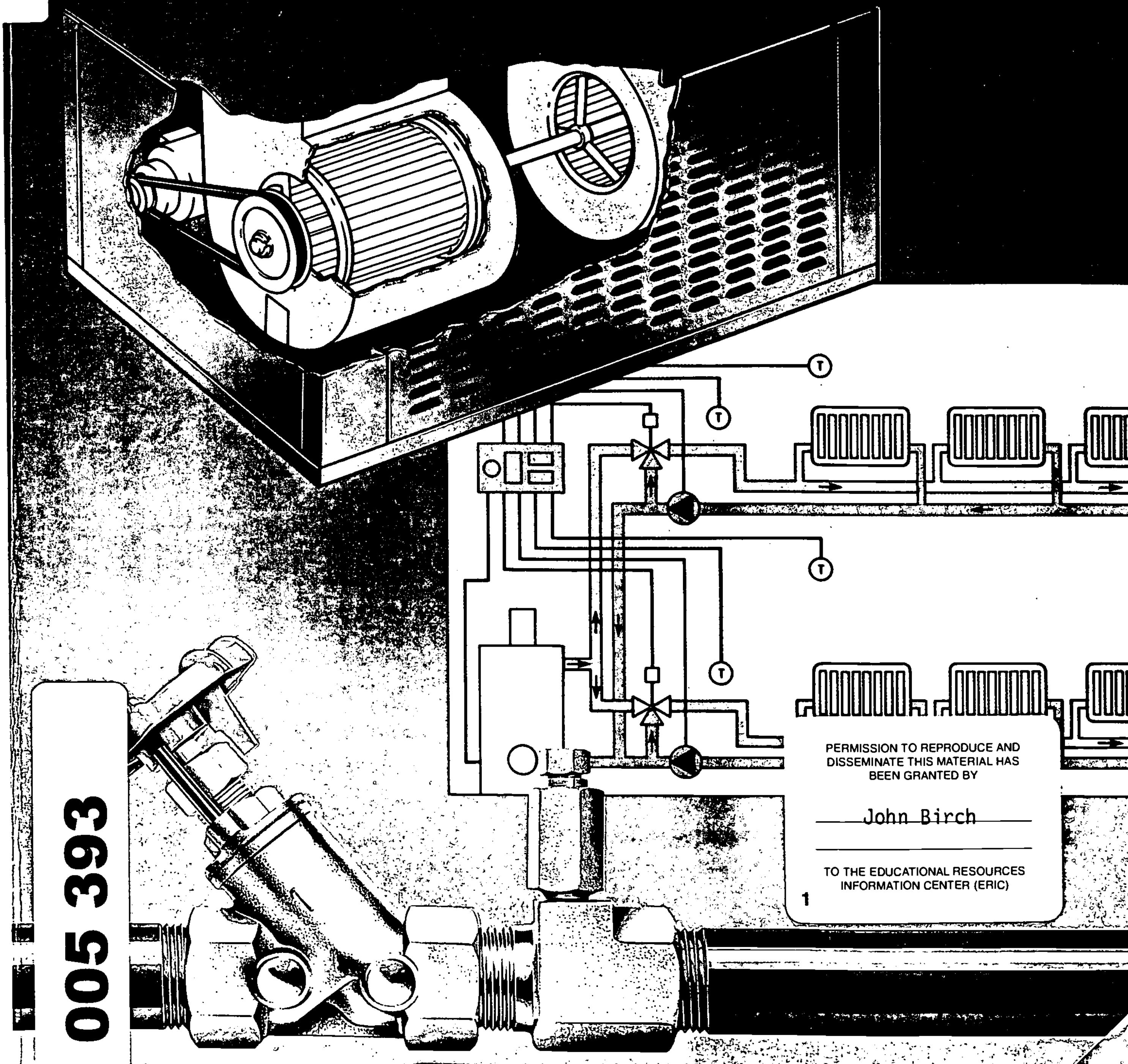
ABSTRACT

School building maintenance must find an appropriate balance between planned and reactive work in order to conserve costs. This document provides ways in which authorities can assess their maintenance requirements and make better use of the resources available. It considers how to deal with problems which have their roots in historical design factors and provides guidance on what action should be taken to prevent future maintenance problems. It also addresses whether to repair or replace equipment by providing guidance for making these decisions. A 6-point plan for avoiding equipment failure is proposed. The appendices, which comprise two thirds of the document, provide a glossary; the principle generic types of equipment in use, common faults which they exhibit and their life expectancy; staff training to ensure the timeliness and quality of maintenance work; checklists for routine inspection and maintenance by school personnel; information on troubleshooting for a range of mechanical services components; information on use of operating and maintenance manuals; and data that include calculating the likelihood of equipment failure, life-cycle costing, forecasting/planning workloads, and the application of new technology to maintenance management and operations in schools. (Contains 26 references.) (GR)

Maintenance and Renewal in Educational Buildings

Maintenance of Mechanical Services



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THE DEPARTMENT OF EDUCATION & SCIENCE

Maintenance of Mechanical Services

Department of Education and Science
Building Bulletin 70

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Summary

Local education authorities currently spend about £114 million per year on maintenance of engineering services in their educational establishments. Maintenance is clearly expensive. Hence it is important for LEAs to ensure that their maintenance programmes are cost effective. A large part of most LEAs maintenance expenditure is currently on reactive work. A large proportion of reactive work makes planning and budgeting difficult and management can be reduced to responding to crises. In order to ensure that the limited financial resources are used effectively, it is important to achieve an appropriate balance between planned and reactive work.

There is also a need to develop policies which would make planned maintenance work more efficient. This bulletin outlines a strategy which can help in this process.

An important part of any maintenance strategy should be a condition appraisal survey. The bulletin proposes a method for conducting such surveys and recommends that LEAs should aim for consistency in the surveys to obtain a coherent picture of the condition of their estate.

The bulletin also addresses the issue of whether to repair or replace equipment. To assist with making such decisions, a repair/replace decision tree is provided.

A powerful tool to assist in taking repair or replace decisions is that of life cycle costing. Guidance is offered on a method of life cycle costing which determines the cost effectiveness of a replacement decision given a particular required payback period.

With the implementation of Local Management of Schools (LMS) many schools will in future be responsible for a lot of the day-to-day and emergency work. The possibility of school personnel being able to undertake some inspection and maintenance tasks is examined and the conclusion drawn that this would be useful. The need to train school personnel for this purpose is outlined and the extent of training recommended. A schedule of tasks which could be undertaken on daily, weekly and monthly bases is provided. A fault tracing chart for use by school personnel is also included. (See Appendix D.)

An important aspect of a maintenance strategy is the avoidance of failure. To assist with this, a 6 point plan to avoid failure is proposed. An appendix on maintainability provides a checklist of design factors that could ease maintenance requirements.

The bulletin considers how to deal with problems which have their roots in historical design factors and provides guidance on what action should be taken to prevent future maintenance problems.

Whilst this bulletin is intended primarily for the local education authorities, much of the advice and guidance would be equally useful to those responsible for other educational buildings including further and higher education establishments.

1 Introduction

1. In terms of the number of premises, schools form a large sector of the property estate of local authorities. Figures for expenditure on the maintenance of engineering services from the maintenance expenditure report for 1986, compiled by the Society of Chief Architects of Local Authorities, indicate that they form the largest sector. The approximate split of maintenance expenditure by LEAs shows that school building fabric accounts for 70% of the total expenditure and engineering services for the remaining 30%. On this basis in 1984/85 LEAs spent £114 million on maintenance of engineering services. Of this about 50%–70% is spent on mechanical engineering services. Figure 1 indicates the level of committed maintenance expenditure by LEAs over the period 1977–78 to 1986–87, at constant prices. The graph shows that expenditure has risen steadily by about 25% over the 9 year period.

2. As a result of the large educational building programmes of the 1960's and 1970's there are now many systems coming up for major repair or replacement and this is adding to the pressure on maintenance expenditure.

3. With the reduction in new building programmes and in the light of financial constraint, there is a need to achieve maximum value for money in the operation of the existing building stock. This can be seen in the context of high energy costs and the increasing need for replacement as equipment reaches the end of its working life. This is particularly so in the case of mechanical services where both energy and maintenance costs are substantial consumers of revenue.

4. The bulletin suggests ways in which the assessment of maintenance requirements can be made

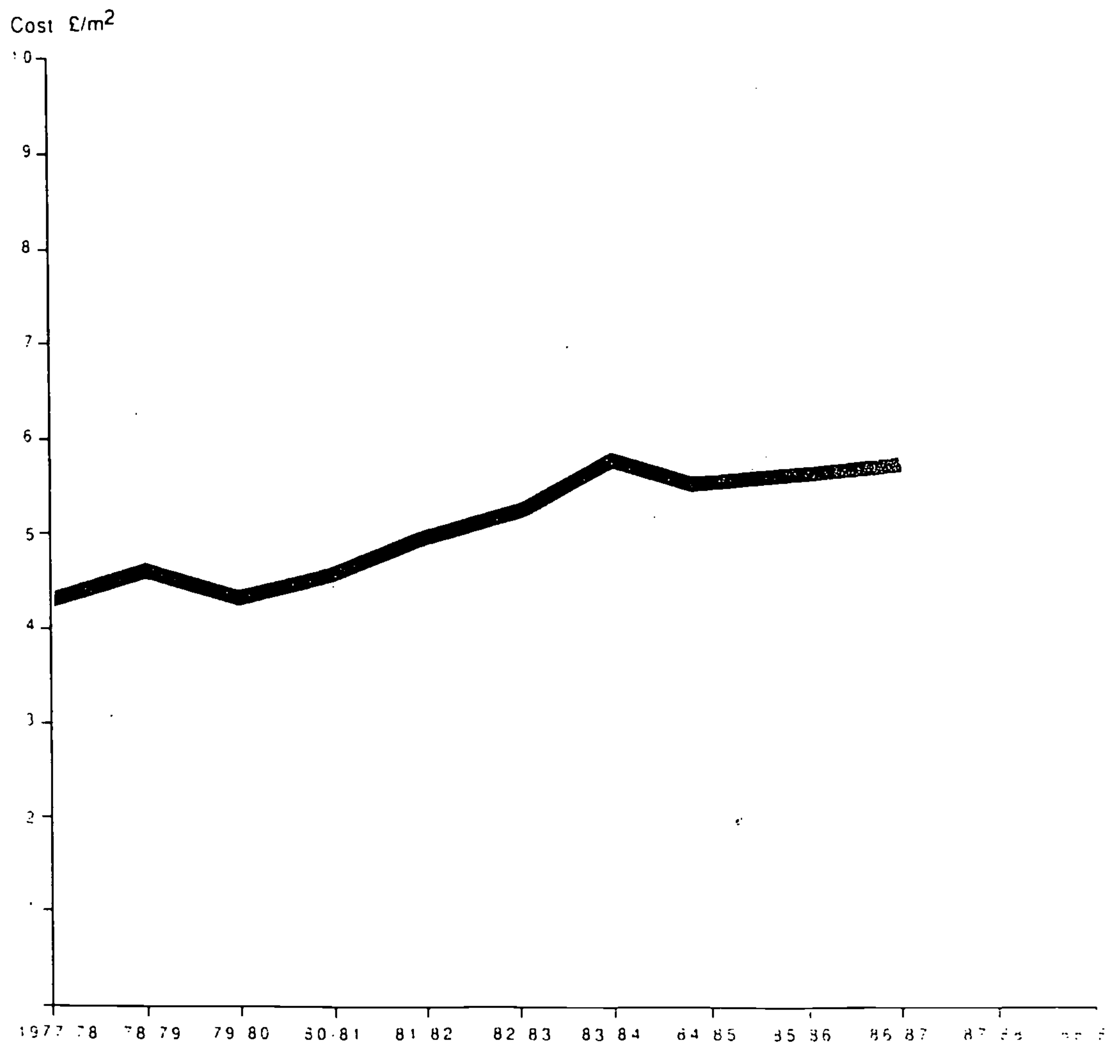

Figure 1: Committed maintenance expenditure at constant prices

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more accurate so that better use can be made of available funds. Particular emphasis is placed on the decision to either replace or retain mechanical services components.

5. The document is based on a study by BSRIA, and has had the benefit of comments from a number of organisations including The Society of Chief Electrical and Mechanical Engineers in Local Government (SCEME), The Society of Chief Architects of Local Authorities (SCALA), The Building Research Establishment (BRE) and the Property Services Agency (PSA). The views in the bulletin are generally supported by the report on 'Maintenance of building services installations in local authority premises' prepared by SCEME.

6. Currently, the maintenance of mechanical services is carried out under 2 headings:
 Planned preventive maintenance
 Reactive maintenance

7. Preventive maintenance is carried out on components which are regarded as *a serious failure risk or for safety reasons.*

8. Design Note 40 *'Maintenance and renewal in education buildings. Needs and Priorities'*, recognises that it is comparatively common for major replacements and renewals in mechanical engineering installations to be carried out on a planned basis, the most usual example being that of replacement programmes for boilers. There is also a growing tendency to replace control systems on a planned basis. However, the life cycle periods for various building service components and systems are imperfectly understood. Analytical methods for assessing reliability and determining the onset of failure are not well developed for building services and are consequently not widely used.

9. At present, too high a proportion of maintenance is reactive. This is building up problems for the future and is not cost effective either in the short term or the long term. As 'reactive' expenditure grows, a situation may arise where maintenance work is almost wholly in answer to a crisis situation, i.e. where lack of maintenance could lead to a hazardous situation and the closure of parts or the whole of a premises.

10. The lack of adequate preventive maintenance may also shorten the life of plant and equipment, leading to increased capital expenditure in the longer term.

11. Allowing equipment to deteriorate to a state where reactive maintenance must be carried out may negate the reasons why a local authority carried out maintenance in the first place. These include compliance with the Health and Safety at Work Act. LEAs and school governors need to bear this in mind when allocating resources. Allowing deterioration may leave plant and equipment in a dangerous state and render the local authority or school governing body potentially liable for negligence. Moreover, if an effective planned maintenance system for major engineering services is not in operation, schools could end up spending a great deal of their delegated finance on the resulting reactive maintenance work.

12. Carrying out maintenance primarily on the basis of emergency action in response to an immediate need may cost significantly more than preplanning the maintenance requirement. Consider, for example, an out of hours call for a tradesman. The rate at which this is charged will be a premium rate. There may be delays in obtaining spares, during the course of which a school may be inoperative or may have to operate using ad hoc measures (e.g. electric heaters in place of the boiler). This may also have a cost effect. If the tradesman is already committed elsewhere, there may be a delay anyway before attendance on the site is possible.

13. Preventive maintenance does not remove the need for reactive maintenance. It does however mean that many operations can be carried out in a more orderly and cost effective manner. Operations can also be scheduled to occur at a convenient time, e.g. in school holidays, rather than at the most inconvenient times (as can happen with emergency maintenance).

14. There are certain activities which are already recognised as requiring a maintenance strategy, the most notable of these is the maintenance of pressure jet burners on oil fired boilers. However this is not enough. There is a need to develop a strategy covering all maintenance work. Such a strategy would require:

- An appropriate balance between planned and reactive maintenance work;
- Information on economic life of components;
- A regular appraisal of condition of systems and components;
- A systematic method for taking decisions on repair or replacement on a cost effective basis;
- An evaluation of life cycle costs;
- A plan to avoid failure.

In subsequent chapters each of these aspects is considered in detail.

15. There are a number of actions which may be taken directly by school personnel. In carrying out these actions, school personnel are actively involving themselves in the economic and efficient operation of their own premises as well as placing themselves in the best position to provide information on required maintenance work. Inspection and maintenance checklists for school personnel are indicated in Appendix D whilst fault tracing procedures are indicated in Appendix E.

16. Maintenance strategy based on the methods outlined in this bulletin offers the potential benefits of:

Better maintenance
More convenient maintenance
More cost effective maintenance

4 Planned preventive and reactive maintenance.

17. Preventive maintenance is the process by which maintenance activities are carried out at predefined intervals in order to arrest deterioration and to minimise the incidence of failures. Ideally, the required maintenance interval should be established so that not only are plant and equipment maintained in an operational condition, but also in the optimum condition.

18. **The advantages of a preventive maintenance system are:**

It allows a prior knowledge of the maintenance effort required on major plant and systems and enables maintenance programmes to be planned in the most effective manner.

By maintaining plant and systems in optimum condition, their life should be maximised, and energy costs reduced.

The long term effect of preventive maintenance should be a reduction in required annual capital expenditure.

19. **The disadvantages of a preventive maintenance system are:**

It is possible to induce faults in plant and systems by carrying out preventive maintenance.

Maintenance is carried out when it is apparently not necessary.

The effect of introducing preventive maintenance is that initially costs may be increased.

Even with preventive maintenance, there will be a substantial reactive maintenance load.

20. Reactive maintenance is that carried out to rectify a fault which has occurred at random. This may be on plant or equipment which is otherwise part of a preventive maintenance programme or on equipment which is typically not covered by such a programme.

21. **The advantages of reactive maintenance are:**

It is carried out only when there is a pressing requirement.

Lower apparent cost initially.

22. **The disadvantages of reactive maintenance are:**

Plant and systems are not maintained at optimum efficiency and as a result energy costs may be increased.

Plant and systems life cycles tend to be shorter leading ultimately to higher replacement costs.

Important environmental and safety requirements may not be met.

Breakdown of plant can result in closure of the school.

23. What preventive maintenance does offer is the possibility to predict, well in advance, the likely resources required for maintenance with the consequent effect that the requirement can be planned to occur as a smooth flow of work.

24. There are other spin off benefits to a preventive maintenance effort which assist in improving the long term cost effectiveness of systems:

a. It is possible to predict the spares requirement enabling components to be held in stock (either by direct labour maintenance or by a maintenance contractor). This could allow bulk buying with improved discounts.

b. The listing of components in an asset register enables easier identification of the range of manufacturers being used. By endeavouring to reduce the number of these, familiarity can be gained with particular component types enabling more effective and quicker maintenance. It also means that the range of maintenance plans required and the number of special tools can be reduced, again improving familiarity.

c. In the long term, it will be possible to link control systems directly to maintenance management systems enabling the automatic production and direction of work orders.

25. Perhaps the greatest long term cost benefit of preventive maintenance is that, since components are better maintained, their life expectancy must be expected to improve.

26. However, it must be accepted that even in the best regulated preventive maintenance programme, reactive maintenance will still be necessary. Allowing a proportion of reactive maintenance may, in fact, be a good idea since it allows a greater flexibility in determining the use of available labour resources.

4 Planned preventive and reactive maintenance

27. There are no quantifiable data to suggest what might be an optimum ratio of preventive versus reactive maintenance work, and any such ratio is bound to vary according to the nature of extent and complexity of the installed services. However, when the reactive element is high in relation to the preventive element local authorities should clearly take whatever steps are possible to ensure that expenditure on preventive maintenance is sufficient to keep reactive maintenance to a minimum.*

* For a fuller discussion of this aspect of maintenance expenditure see *Maintenance and renewal in educational buildings*, A & B Paper No 7, DES, 1984.

28. Data currently available on the economic life of components tend to be limited in scope; much are related to continuously operated plant which is subject to complete preventive maintenance programmes.

29. Since schools are intermittently used, engineering systems being closed down both overnight and for school holidays, and since they are often not subject to comprehensive maintenance programmes, the application of data on the economic life of components should be treated with caution.

30. Table 1 gives anticipated economic life expectancies for complete M & E installations and Table 2 gives them for component parts of the installations. These have been derived from published data and also draw upon the experience of engineers responsible for maintenance in schools. The figures quoted should therefore be regarded as based on assessment rather than direct measurement.

31. The table may be used to provide outline guidance on the anticipated economic life of a new component or system which is subject to a comprehensive maintenance programme. It should not be used however to assess the remaining economic life of a component or system which has already been in service for some time and/or whose maintenance history is uncertain.

32. The anticipated economic life expectancy is not the only criterion which should be used in determining whether to continue to maintain a component or to replace it. Other criteria also need to be considered and include:

- The current condition of the component; whether it is safe and reliable, or can be made safe and reliable.
- The cost of maintaining an existing component over a period of time as compared with the capital and maintenance costs of a replacement component.
- Reduction in energy usage by replacing the component. For boilers, this may be assessed by a comparison of combustion efficiencies. An assessment based on these criteria may indicate the need for replacement earlier than shown in the tables.

Table 1 Anticipated economic life expectancy of complete M & E installations.

Component	Life expectancy
Boilerhouse installations:	
with cast iron sectional boilers	25–30
with mild steel welded boilers	15–25
with mild steel welded boilers, light design	10–15
Internal electrics	30
Gas	30
Heating	30
Hot water supply	20
Mains, external:	
pipework in ducts	20
pipework above ground	25
Mains, external:	
underground cables	30
overhead lines	25
Ventilation	25

Table 2 Anticipated economic life expectancy of components.

Component	Life expectancy (years)
Boiler (*Note 1)	
cast iron sectional	20–25
mild steel welded	15–20
mild steel welded, light design	10–15
Burners	
Pressure jet	15–20
Atmospheric	20
Automatic stokers	10–15
Boiler refractories	8
Boiler tubes	8
Flues:	
Mild steel	8–15
Stainless steel	25
Pumps:	
Centrifugal	20–25
In-Line	10
Submersible	20
Controls (*Note 2)	10
Pipework and fittings:	
Internal steel	20–30
External steel buried	10–15
Internal copper	25–30
Cast iron	40
Insulation and coatings:	
Internal	25
External	15
Buried	10
Valves	
Iron	20
Bronze	25
Glanded	20
Glandless	25
Space heating:	
Cast iron radiators	20–25
Steel panel radiators	10–15
Fan convectors	15–20
Calorifiers/Heat exchangers (copper)	20

Table 2 Anticipated economic life expectancy of components. *(continued)*

Component	Life expectancy (years)
Tanks:	
Water, steel	25
Water, non-metallic	30
Oil storage, steel	25
Fans:	
Axial	15
Centrifugal	20
Propellor	10
Kitchen equipment:	
Industrial	15
Domestic	10
Lifts:	30
Batteries:	
Lead acid (static)	8
Nickel alkaline	20
Doors:	
Power operated	20
Cold room	20
Ductwork, metal	30
Electrical rotating machines (generally)	25
Sewage ejectors	20
Lights:	
Internal fittings	20
Street fittings	20
Electrical motors	30
Motor control gear and contactor panels	15
Machine tools (generally)	30
Switchgear, distribution:	
Indoor	30
Outdoor	25

Note 1: This is the working life expectancy. Economic life expectancy may be dictated by fall off in heat transfer efficiency which can merit a replacement time less than that indicated.

Note 2: Technological advance may render controls obsolete in a shorter period of time than indicated. The most critical factor may be the availability of spares.

6 Condition appraisal

33. Condition appraisal involves the subjective assessment of the current condition of a component or system. It may be carried out in the absence of more definitive information from instrument based condition monitoring or from the analysis of work orders returned in a preventive maintenance programme. By such an appraisal, it is possible to determine which equipment is in good condition, which requires maintaining (and when) and which should be replaced, with an assessment of when replacement should take place.

34. Appraisal is carried out by means of a survey of the installation whereby the condition of the various elements is assessed according to a defined method of classification. The survey should be carried out by an experienced engineer with knowledge of the building and the engineering plant. While the precise method of classification may vary there are two aspects of particular importance:

a. There should be enough classes to allow a reasonable discrimination between a range of conditions.

b. There should not be so many conditions that the person carrying out the survey can be confused by the range of choice.

35. Since condition appraisals may be carried out on many schools it is important to ensure that the method of appraisal is consistent throughout. In part this is achieved by using a standard condition classification. It is further enhanced by having a common means of identifying the components to be surveyed. Clearly, not every school will have every component on the list installed. This does not matter, consistency does.

36. By obtaining consistency in the reporting of condition appraisals, it is possible to collect together data regarding all schools within a particular area and consider the general condition of engineering services. This might, for example, show that a particular type of component is causing problems; this can then be investigated. The predominance of a particular classification could lead to the establishment of a maintenance or replacement policy to take care of the problem.

(a) Condition appraisal form

37. The model condition appraisal form shown in Figure 2 lists criteria which can be used in the assessment of an individual installation or in a range of installations.

38. The information at the head of the form identifies the installation uniquely together with the date of the appraisal and the person who carried it out. Using this information, installations of a similar type can be grouped together for examination whilst the survey data provide a reference point for a year to year assessment of changes in condition.

39. Since different engineers may use different subjective criteria in appraising an installation, some adjustment may be required in individual findings if installations are to be compared on a consistent basis.

40. The appraisal form identifies a range of different system and component types. This is important because whilst a system may be generally sound, particular components may require corrective action. The systems and components identified include those typically found in educational premises.

41. The reference given against each system and component item provides a means by which these may be uniquely identified within the data record. This reference may also be designed to incorporate a generic element which can be used to identify items of a similar type across a range of installations (e.g. atmospheric gas boiler).

42. The installation date of a system or component is important since it immediately indicates age. However the age of an item should not be taken as the only criterion for replacement; a well maintained component may have a longer useful life whilst one which is poorly maintained may have a shorter life expectancy.

43. The current appraisal is clearly the most important aspect since it identifies the condition of an item at a point in time and leads to conclusions regarding the action to be taken. Table 3 indicates a model for a condition classification system. The findings of the previous appraisal are also important since these can guide the engineer as to the extent of inspection required. Items having a low classification may

This form to be used only for the subjective assessment of the condition of components and systems according to visual inspection by the engineer.

School name ____________________

Property reference ____________________

Survey date ____________________

Appraisal by ____________________

Area ____________________

SPACE HEATING

Systems	Ref	Installed	Previous Appraisal	Current Appraisal	Action	Suggested Cost of Putting right
Air handling/conditioning						
Fan convector systems						
Natural convector systems						
Radiator systems						
Floor coil systems						
Ceiling systems						
Gas convector systems						
Other (1)						
Other (2)						

Figure 2: First page of condition appraisal form

For complete form see Appendix K

warrant more detailed inspection; this may also be the case with older items.

44. The column entitled 'Action' is intended for use by the engineer in recommending what course of action should be taken in respect of a particular component or system. 'Such comments might include:

Urgent replacement required
Urgent maintenance required
Replace control box

45. Although a standardised set of comments could be derived for describing recommended actions this is not proposed.

46. It is recommended that the engineer completes the column on the 'Suggested Cost of Putting Right'. Costs are ultimately required for planning purposes and give an immediate indication of the extent of work required. Costs should include for any work associated with a maintenance action such as draining down, testing etc.

47. The 'Action' and 'Suggested Price' columns provide the information required by the engineering maintenance department to determine which actions should be taken in the light of budget constraints.

48. On completion of the condition appraisal form, it is suggested that the engineer should include some general comments on matters such as the general condition of the installation, access for maintenance, and any difficulties likely to be encountered.

49. The completion of appraisals enables:

Evidence of required expenditure to be provided to local authority finance departments.

The development of standard specification and/or standard buying policies.

6.2 Period of appraisal

50. Ideally, condition appraisal of systems should be carried out every year. However, where the available resource of experienced engineers is insufficient to allow this, the following periods of appraisal are recommended:

Where the condition classification is predominantly 'reasonable' or 'good', allow a maximum period of 3 years. This should be shortened if possible.

Where the condition classification is predominantly 'poor' to 'bad', allow maximum period of 1 year.

A hazardous classification of a component or system should be attended to immediately.

6.3 Co-ordination of appraisal

51. Where possible appraisal of the condition of mechanical services should be carried out in conjunction with similar appraisals of electrical services and the building fabric. Ideally, the programme of appraisals should be under the direction of a programme co-ordinator and all appraisal data stored in a common system, which could be computer based.

52. Where maintenance work is required as a result of appraisals, a co-ordinated package of mechanical, electrical and fabric work should be prepared. This should be done to prevent unnecessary additional work which might be caused by, for example, an electrical rewire occurring after decoration.

6.4 Appraisal of hidden services

53. The appraisal of services which are hidden from view or buried presents particular problems, since a periodic visual inspection may invite significant disruption to school activities. Such disruption may generate more problems than it solves.

54. Consequently, hidden service appraisals should be carried out as the opportunity arises, rather than simply at periodic intervals. These should be co-ordinated with other work wherever possible.

55. Alternatively, a local authority may wish to appraise the condition of hidden services over a range of sites at a particular time.

6.5 Analysing condition appraisal data

56. Once condition appraisals have been carried out, it is necessary to analyse the data presented to determine the required actions. Analysis may be carried out either manually or using a computerised database.

Table 3 Condition classification.

Condition	Term	Description
1	HAZARDOUS	Requires immediate attention of an emergency nature. May mean closure of a section of the building as being dangerous if not immediately dealt with.
2	BAD	May not be in a dangerous condition but is in a bad condition and work to whole system should receive the highest priority.
3	PART BAD	In bad condition in parts only. Work on these parts should receive a high priority.
4	POOR	Unsatisfactory condition. General repairs or partial replacement required in the near future to prevent deterioration of the component.
5	REASONABLE	Satisfactory; working as intended, does not require other than routine attention. Review next time.
6	GOOD	As new. (This should be used as a rare accolade).

6.5.1 Manual analysis

57. In this case, the various appraisals have to be collected together, ordered and the data required transcribed in such a form as to facilitate analysis. With manual analysis, the aim must be to keep the task within reasonably defined boundaries so as to enable its satisfactory completion.

58. Where the intention is to use a computerised database at some point in the future, the discipline of collecting information together in a structured manner and having an operative system of analysis in place will greatly assist the transition from manual to computer working.

6.5.2 Computer analysis

59. Use of a computerised database can greatly assist the analysis of information collected together in a structured manner, not only for the current condition of plant and systems but also in respect of historical information.

60. The computer database may be regarded as a form of electronic card index. Having once entered the data, the user can then ask a series of questions and obtain reports on various aspects such as:

LIST FOR CLASS = 'HAZARD'

or

COUNT FOR CLASS = 'HAZARD'

61. The first of the above commands will list all records in the database which are given the classification, HAZARD (or 1 from the condition classification given) whilst the second command will simply count how many records have this classification. (See Figure 3.)

62. In the majority of circumstances, the range of reports required will not significantly vary from year to year. Many of the more popular database programs now available allow the user to predefine and store report configurations and even allow the definition of forms for data entry. This aspect may be used to assist the work of the data entry operator.

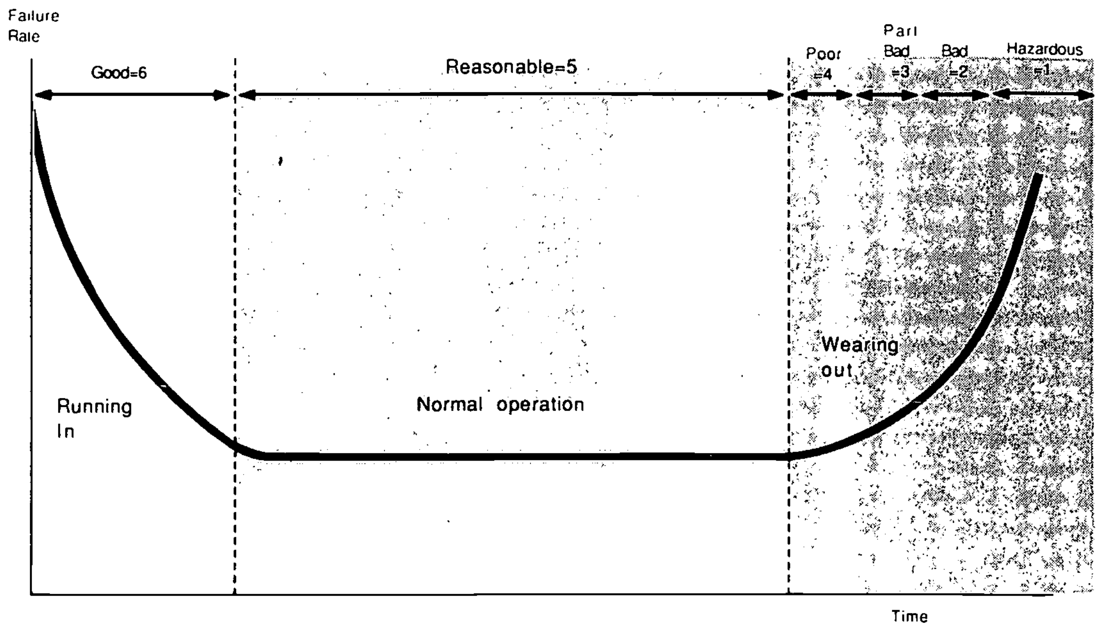

Figure 3: Approximate relationship of condition classification with bath tub curve

63. The advantage of using a computer database is that once the initial system has been created with the minimum set of information, it can be expanded to take account of other factors. These could include cost information, names of contracted maintenance specialists and so on.

64. One of the most useful facilities of modern computer based systems is that they frequently allow the output of information in the form of graphs and charts. Thus, it should be possible to group condition classes into priorities (or say priority 1, 2 and 3 as in the Design Note 40 Maintenance Expenditure report) and determine the proportion of the total engineering plant and systems requiring urgent attention. Alternatively, graphical output may be used to analyse the year by year trend for the condition of an item (i.e. a simulation of the bath tub curve).

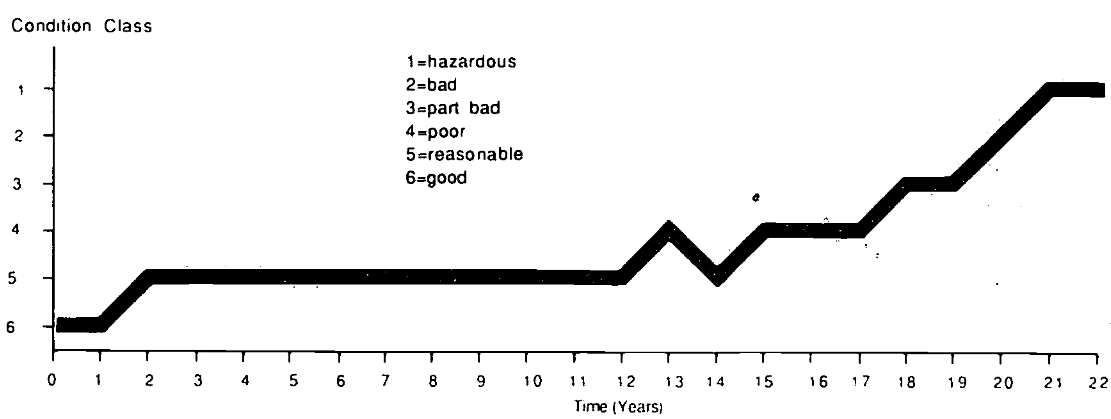

Figure 4: Simulation of condition class trend to bath tub curve

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6.5.3 Simulation of bath tub curve

65. For a description of the bath tub curve see Appendix H. It is possible to use data on the condition of plant and systems to simulate the bath tub curve in the absence of actual failure rate data. This can be done by plotting condition class on the vertical axis and time on the horizontal axis. The occurrence of a bad or hazardous classification or their contribution over a period of time are signals that the repair/ replace decision may be imminent. It should be noted that the early stages of plant life (according to condition classification) do not conform to the bath tub curve and consequently should be ignored in terms of failure rate.

Figure 4 shows how condition class is plotted against time and indicates the progression into the hazardous classification area in a similar manner to the bath tub curve.

This graph is an example only and is not prepared from real data.

7 Repair or replace decisions

66. The decision on whether to repair or replace individual components or complete systems (see Figure 5) must be based on the answers to a range of questions:

- What is the age of the component and how does it compare to the expected life indicated in the life expectancy table? If the age is well within the life expectancy then the tendency will be to consider repair; if the normal life expectancy is running out (or has been exceeded) then the tendency will be to replace.

- What is the current condition as indicated by the condition appraisal and what trend is exhibited by earlier appraisals? If the trend shows that the condition is normally reasonable whilst the present condition appraisal shows a condition class which requires work then the tendency will be to consider repair. If the trend shows that work has been continually required for some years and that despite this the condition is worsening then the tendency to replace will be greater.

- Are spare parts still available? In areas of rapid technological change such as automatic controls, repair is clearly not feasible if spare parts cannot be obtained. This may dictate replacement even when condition appraisal indicates repair.

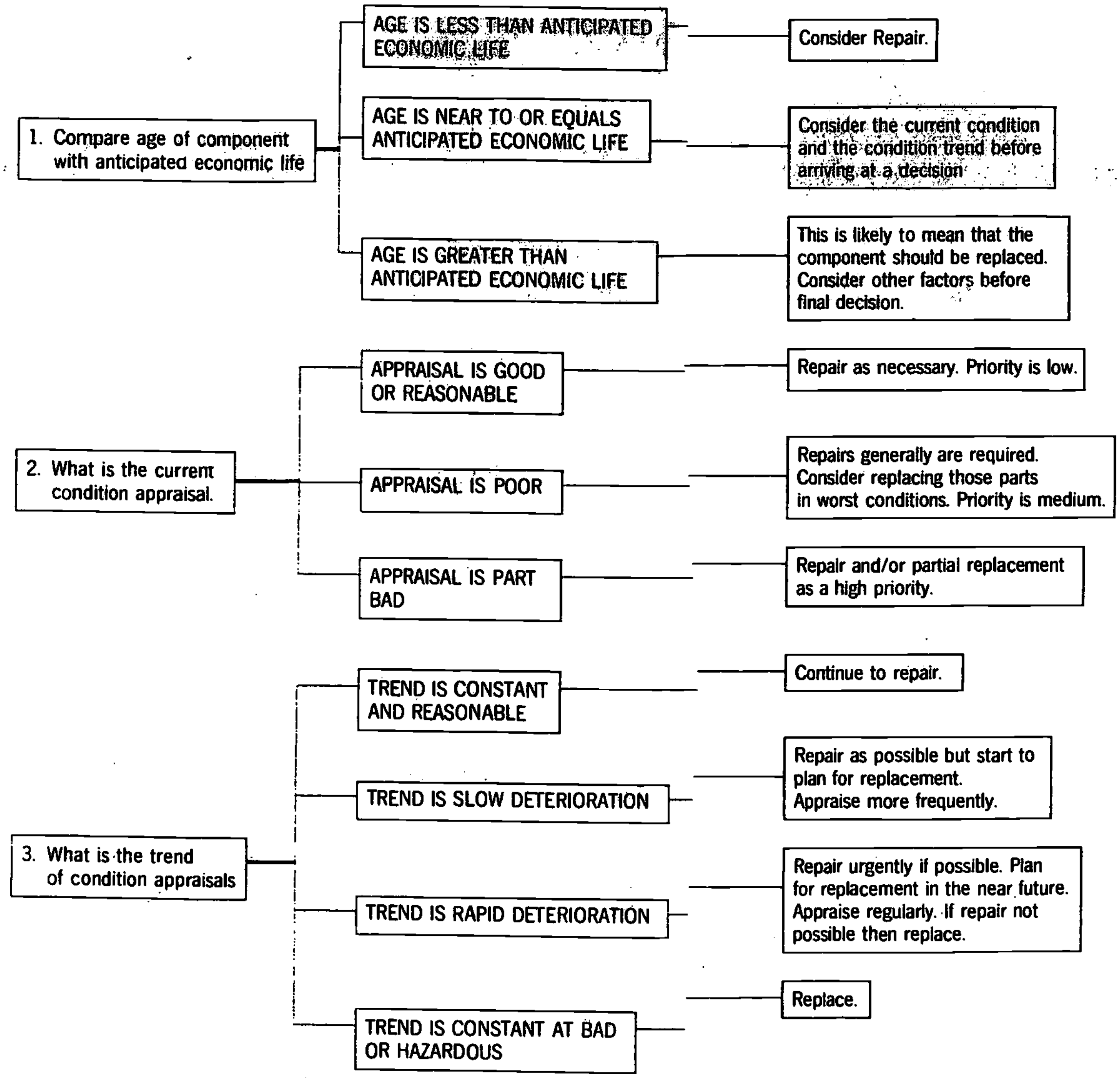
- What is the trend in maintenance costs and does replacement offer a cost benefit which can be demonstrated within an acceptable period of time? Such life cycle cost analysis is useful in local authority maintenance departments in forward planning of maintenance programmes. It will be particularly relevant where plant is ageing or spares are becoming rarer and condition appraisal indicates a greater requirement for work. The use of life cycle cost analysis may indicate a shorter life than that indicated by the life expectancy tables.

- Are there any financial constraints affecting maintenance decisions? Whilst engineering factors may suggest that replacement of a component is preferable, financial constraint may dictate that a 'make do and mend' repair is carried out. It is for this reason that replacement decisions should be prioritised as being essential, required or advisable. Thus within a given budget, the intention should be to carry out all essential work and a significant proportion of that required. In this case, advisable items must be allowed to deteriorate to a required or essential replacement condition.

- By prioritising replacement requirements, is it possible to smooth financial requirements over a period of years in line with likely budgetary provision? A consistent budget is more likely to gain favour than one which shows erratic jumps because a large number of replacements are required in a particular year.

- Apart from maintenance cost considerations, can replacement be justified on the grounds of savings in energy from the use of more modern equipment? A typical example of this might be the installation of a modern high efficiency boiler operating at a level of 80% efficiency to replace an older unit with an efficiency of 50–60%. Where such energy savings can be achieved with an acceptable payback period, then the additional cost of replacement may well be justified.

Figure 5 Repair/replace decision chart



4. Are spare parts still available	SPARE PARTS ARE AVAILABLE	Repair.
	SPARE PARTS ARE NOT AVAILABLE	Replace even if all other factors indicate otherwise. This is an indication of rapid technological advance.
5. What are maintenance costs as a proportion of capital cost.	PROPORTION IS LOW	Continue to repair.
	PROPORTION IS HIGH	Check Life Cycle Costing. Indications are that replacement may offer a significant economic benefit.
6. Does Life Cycle costing indicate that replacement offers an economic advantages over continuing with present situation.	REPLACEMENT OFFERS NO ADVANTAGE	Continue on a repair basis.
	REPLACEMENT AND CONTINUATION COSTS ARE CLOSE	Check also current condition before committing to a decision.
	REPLACEMENT OFFERS SIGNIFICANT ADVANTAGE	Replace.
7. Are there any financial constraints affecting maintenance decisions.	CONSTRAINTS EXIST	Prioritise replacement decisions and take those which are within financial constraint. Develop a replacement plan over the next few years as a 'business case'. Aim for consistency in expenditure.
8. Can replacement be justified on savings in energy use available from new equipment.	SAVINGS ARE JUSTIFIED	Replace.
	SAVINGS ARE MARGINAL	Continue on a repair basis and monitor condition trend carefully.

8 Life cycle costing

67. Often before repair or replace decisions can be taken it is necessary to carry out life cycle costing. This provides a measure of the long term costs of a given course of action compared with other possible courses of action. In particular, it can be used to assess the long term cost implications of doing something as opposed to doing nothing. In essence, an action is cost effective if its life cycle costs are lower than an alternative course of action (or no action). The method and an example of life cycle cost analysis is included at Appendix I. Life cycle costing can be carried out in a number of different ways. The method outlined in Appendix I uses a Discounted Cash Flow and Net Present Value technique; however other methods like Annual Equivalent Value can also be used.

68. The failure of a component in a building services system can be seen in terms of three elements.

Cause: may be inherent either due to a manufacturing fault or due to normal wear and tear:

Manufacturing fault – misalignment of pump or fan impellers.

Wear and tear – progressive wear of bearings or blockage of filters.

Onset: may be either sudden or gradual:

Sudden: snapping of belts on belt driven pumps or fans.

Gradual: loosening of belts on belt driven pumps or fans.

Degree: may be partial or complete. In a building services system, a component may partially fail and still appear to be operational.

Partial: inability of boiler to meet load; build up of air in radiators.

Complete: electrical motor overload.

69. Where failures occur, it may be possible to establish a pattern to describe the most common types. By so doing, attention can be given to rectifying common faults in a manner to improve reliability. This might be done by replacing a part with one of higher quality, increasing the frequency of maintenance or changing the operating parameters of the system to avoid inducing the fault (as might be the situation in the case of frost damage).

70. Figure 6 entitled "Gradual failure" describes the progressive inability of a component to maintain the required duty as it ages. Failure may be said to occur when the actual duty capability is less than the required duty capability.

71. The best way of dealing with failure is to try to avoid it occurring in the first place. Clearly this cannot always be achieved but attention to certain factors can assist.

a. Components installed should be of an appropriate quality and rating for the design duty. They should not be allowed to perform above their rated duty.

b. Give as much maintenance attention to the simple components in a system as to the more complex. Remember that the failure of a simple component can affect the operation of the system in as drastic a way as the failure of a complex component.

c. Consider the possibility of adding redundancy. This may be regarded as providing an alternative component and flow path in a system such as a run and standby pump system or additional modules in a modular boiler system.

d. Set up a programme to assess the operational condition of components in a system on a regular basis. In particular, attention should be given to the condition of short life or frequent maintenance items, such as filters, lubrication, etc.

e. Identify clearly which aspects of maintenance can be carried out according to the limitations of the human resource available. For instance, staff in a caretaking role may be able to carry out certain maintenance actions but should not be allowed to carry out others. For instance, energy efficiency controls may be excluded from a caretakers' maintenance responsibility.

f. Ensure that the operating parameters of the system are set at a suitable level so as to avoid the risk of breakdown or failure by such mechanisms as frost damage, overheating, high or low pressure, no flow conditions and the like.

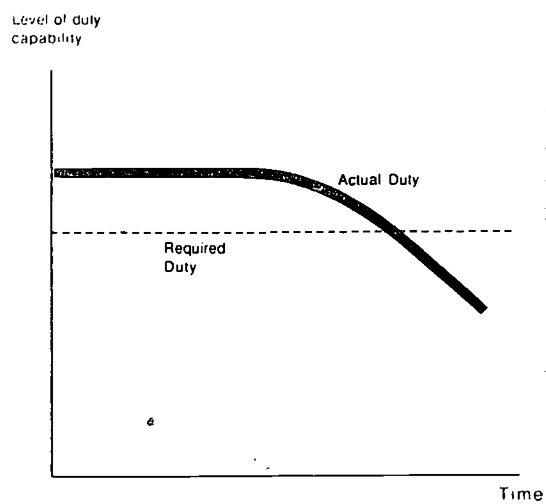


Figure 6: Gradual failure

Glossary

Anticipated economic life expectancy

The anticipated life expectancy of a component during which its continued operation may be demonstrated as being of greater economic benefit than its replacement.

Capital cost

The initial purchase cost of a component or system.

Condition appraisal

A subjective assessment of the current condition of a component achieved by visual and other inspection personally carried out by an inspector.

Condition based maintenance

Maintenance carried out as a result of a component or system having been observed to be operating at a particular limiting condition. Condition may be observed by condition appraisal or condition monitoring.

Condition classification

A rating on a defined scale given to a component or system as a result of a condition appraisal inspection.

Condition monitoring

The monitoring of the values of particular variables associated with a component or system to determine whether and when maintenance is actually required. The values taken are properties of an indicator such as lubricant temperature, bearing shock, vibration, etc; readings may be taken manually, using instruments or by using a sensor attached to a building energy management system.

Corrective maintenance

Maintenance work carried out to restore an item which has ceased to meet an acceptable condition.

Emergency maintenance

Maintenance carried out in response to an immediate necessity at a particular time to avoid serious consequences. (See also corrective maintenance.)

Failure

The breakdown of a component or system such that it does not carry out the required function.

Life cycle cost

The total cost of a component or system over its complete life including the initial capital cost and all recurring costs of operation and maintenance. Life cycle costs are usually expressed as a present value whereby a percentage is allowed for future depreciation of cash value (discount factor).

Maintainability

The characteristic of design and installation indicating the measure of ease and rapidity with which components and systems can be retained at a specific level of performance.

Maintenance target ratio

For schools under the control of local authorities, the ratio of preventive maintenance cost to reactive maintenance cost (both costs being expressed as a percentage of the total) which is considered to provide an optimum use of available resource.

Pay back period

The time after which the total of capital, operating and running costs of a replacement component or system are less than those of the component or system which has been replaced.

Planned maintenance

Maintenance work organised and carried out with forethought, control, and the use of records to a predetermined plan. It may include cyclical maintenance.

Preventive maintenance

Maintenance work carried out at predetermined intervals to reduce the likelihood of an item not meeting an acceptable condition.

Reactive maintenance

This is essentially day-to-day maintenance, in that its purpose is to deal with jobs as they arise (eg due to breakages, breakdowns, vandalism, etc), but includes emergency maintenance.

Reliability

The probability that a component or system will perform its intended function for a specified period under stated conditions. Reliability may be inherent (built into the design) or achieved (resulting from a maintenance programme).

Running cost (also operating cost)

The recurring costs of a component or system subsequent to its purchase and installation.

Appendix B

Mechanical services system components

Whilst the range of manufacturers and suppliers of components installed within educational premises is wide, the range of generic types of components is much narrower. Under the heading of main component types, this Appendix considers which are the principal generic types in use, common faults which they exhibit and highlights the expected life. Figures for useful life are drawn from the component life expectancy table.

B.1 BOILERS

There are a number of different types of boiler commonly in use in education premises and these use a variety of different fuel types. The types in most common use are cast iron sectional boilers and steel water tube boilers.

Fuels and methods of firing most frequently used are.

Natural gas	atmospheric burners pressure jet burners
Liquefied petroleum gas (gas)	atmospheric burners
Oil	pressure jet burners
Solid fuel	automatic stokers

Common faults (see also fault tracing chart)

The most common fault on boilers fitted with pressure jet burners appears to be the failure of the burner control box. Typically, this is a plug in unit and the fault can be easily rectified by exchanging the control box for a new unit.

Frequently, control and limit thermostats go out of calibration or fail. In the case of the control thermostat this will cause either high or low flow temperature. In the case of the limit thermostat, boiler lockout may ensue. If the fault on the control thermostat causes the flow temperature to become too high then the boiler may again lockout on the high limit thermostat.

In the event of failure of both the control and the limit thermostat, or the limit thermostat allowing the temperature to rise too high, then some of the water will evaporate into steam and an effect known as 'kettling' will be observed. This is a sound similar to a kettle boiling.

In cases where the boiler output appears inadequate, this may be caused by dirt in the burner or by inadequate air being available to the burner. In either case, the burner should be overhauled.

Useful life

(see also component anticipated economic life expectancy)

The life of a boiler will vary according to its type, the extent of use and the extent of maintenance provided over its life cycle. It should also be borne in mind that the useful life of a burner will be different to that of a boiler and that burners are more sensitive to the maintenance regime than the boiler.

A number of local authorities consider the normal life of a boiler to be 20 years and plan their boiler replacement programme accordingly.

Figures for life cycles are usually quoted for continuous use with rigorous maintenance. In such cases, a factor is often applied to the figures for intermittent use to extend the life. It is considered that the normal maintenance regime adopted in schools is such as to make life cycles approximate to those of continuous use even though the actual operation is normally intermittent.

Boilers

Cast iron sectional	25–30 years
Mild steel welded	15–25 years
Mild steel welded (light design).	10–15 years

Burners

Pressure jet (gas or oil)	15–20 years
Atmospheric gas	20 years
Automatic stokers	10–15 years
Boiler refactories	8 years
Boiler tubes	8 years

Flues

Mild steel	8–15 years
Stainless steel	25 years

B.2 PUMPS

Circulating pumps are either centrifugal or in-line. Centrifugal pumps may be either belt driven or direct driven whilst in-line pumps are direct driven.

In older schools, boilerhouses are frequently below ground level and are consequently fitted with sump pumps to dispose of accumulated water.

Common faults

(see also fault tracing chart)

Where the pump is of the belt driven centrifugal type, the most common fault is that the belts are not tensioned correctly or that they have become worn due to misalignment of the pulleys. In the case of them not being tensioned correctly, this can be dealt with by adjusting the motor position on the slide rails. In the case of misalignment of the pulleys, they should be realigned and new belts fitted.

Leaking glands is a frequent problem with pumps and this can be corrected by tightening or replacing them as required.

Air in a water system can damage pump impellers and consequently should be vented whenever necessary. In pumps, it sounds as though small bearings are hitting the impeller.

With in-line, canned rotor, pumps, the most frequent problem is that they have been fitted incorrectly. The drive shaft of this type of pump should be horizontal, not vertical.

With submersible sump pumps, there are two major problems. The first of these is that the inlet can become blocked with debris which should be frequently removed. The second is that the float switch can fail. This will manifest itself either as a flooded boilerhouse or a burnt out pump motor (and flooded boilerhouse).

Useful life

If maintained properly, the life of a pump should be quite long. In the case of a centrifugal pump, it should be at least as long as that of the boiler whilst an in-line, canned rotor, will have a shorter life expectancy.

Centrifugal Pumps	20–25 years
In-Line Pumps	10 years
Submersible Pumps	20 years

B.3 CONTROLS

Controls can cover a variety of functions:

- **Compensated heating circuits**

  A 3 way mixing valve is modulated according to outside temperature sensed by an externally mounted thermostat. A strategically located room thermostat (if incorporated) feeds back signals to the controller to indicate when internal requirements are satisfied. Since the flow water temperature varies, radiators are usually fitted on compensated circuits.

- **Constant temperature heating circuits**

  In this case, the flow water temperature remains constant but the water volume is allowed to vary. A sensor is fitted into the flow main and causes a 3 way diverting valve to modulate, thus varying the flow volume. Fan convectors are used on constant temperature circuits since they will blow cold air if fed with flow water below a particular temperature.

- **Frost protection**

  A frost thermostat senses the outside temperature. If the temperature falls below a certain level, the switching action of the thermostat causes the pumps to come into operation to maintain a flow through the water circuits.

- **Return water protection**

  Low return water temperatures can cause boiler problems through back end corrosion. To protect against this, a return water thermostat may be fitted to cause a diverting valve or shunt pump to operate to raise the return water temperature.

- **Boiler control and limit**

  A control thermostat will cause a boiler to switch on and off at a preset temperature. The high limit thermostat will cause the boiler to lockout as a protective measure if the flow temperature from the boiler is too high.

  Boiler optimisation

  Increasingly fitted in place of time clock operation, optimisers are intelligent controls which can determine the amount of preheating required for a given occupancy start time and a particular outside temperature. By so doing, the switch on time of the boilers is varied rather than having a fixed start time as would be the case with a time clock.

- **Boiler sequencing**

  In situations where there are a number of equally sized boilers, boiler sequencing is used to vary the sequence in which boilers fire to meet a given load. By so doing, the extent of wear on all boilers can be evened out, and the load can be increased in steps.

- **HWS control**

  On hot water service systems, a rise in temperature of the hot water flow can cause a 3 way diverting valve or a 2 way valve to modulate to restrict the flow through the heating coil.

Local controls are more particularly concerned with affecting the heat output in particular locations. Two principal types of local control are worthy of mention.

- **Thermostatic radiator valves**

  Typically these have a built in sensor and the temperature at which they are required to switch on/off can be varied by turning the sensor head. These should not be installed in the same room as heating control sensors.

- **Fan convector control thermostats**

  Typically located in the return air stream of the fan convector; the control thermostat causes the fan to switch off/on depending on whether the return air is at the required temperature or not.

Common faults

Probably the most common fault with control systems occurs when thermostats go out of calibration. Whilst still operating, they are in fact doing so at incorrect values which can be misleading and inefficient in terms of energy use.

Coming shortly behind calibration as a problem is when thermostats fail altogether e.g. when a control thermostat fault occurs on a fan convector, the result may be that the fan operates when water is at a lower than required flow temperature. This has the effect of cold air being blown into the space.

The most common fault with thermostatic radiator valves is physical damage. These are not generally recommended for secondary schools.

As a general rule, the electrical/electronic aspects of control systems are extremely reliable. It is the mechanical parts of the systems which require maintenance attention.

Useful life

The information available indicates that the useful life of a control system is in the region of 15–20 years. In practice, this figure is difficult to justify since this area, more than any other in building services, is being affected by rapid advances in electronics technology. The most modern control systems are effectively fully computerised.

Thus the critical factor in the useful life of a control system is the period over which suppliers continue to make spare parts available. Where control is fully local, then the life may indeed be the 15–20 years quoted. For central boilerhouse control, the maximum which can reasonably be expected, given technological change, is 10 years and the reality may be less than this.

B.4 PIPEWORK, FITTINGS, INSULATION AND VALVES

In this case, the range of items concerned is as follows.

- **Pipework and fittings**
  Black mild steel
  Galvanised mild steel
  Copper
  Cast iron

- **Insulation**
  Mineral fibre
  Mineral wool
  Asbestos
  Calcium silicate
  Insulation coverings

- **Valves**
  Isolating valves
  Control valves
  Safety valves
  Radiator valves

- **Locations**
  Internal (exposed or below ground)
  External (exposed or below ground)

Common faults

Pipework and fittings

The most common fault with pipework is that of leakage. On steel pipework, this is most likely to be caused by corrosion whilst on copper pipework, joint failure is likely to be more common.

The most common fault reported on steel pipework was that of corrosion of pipework buried in the ground. Here, the covering protection of the pipe can go brittle and crack after a time allowing water penetration which leads to corrosion. The location of a leak can be difficult in these circumstances.

Internally, where pipework rises up from below ground and particularly in wet areas such as toilets and shower/changing areas, corrosion can occur at the point where the pipe becomes exposed. This is again due to contact with water. This can be prevented by the fitting of sleeves which stand proud of the floor.

A well made joint on copper pipework should be very reliable. However, cyclic strain on compression fittings can cause the 'olive' to progressively fail giving rise to leaks.

Copper or copper alloy fittings and steel pipework should not be mixed due to the possibility of dissimilar metal corrosion occurring.

It is noticeable on galvanised steel pipework, that where the galvanised coating is removed, corrosion can occur rapidly at the point of removal.

The presence of leaks on screwed fittings, particularly in boilerhouses, is noticeable as a fault. Quite often this cannot be put down to any of the above reasons. It is most probable that where this occurs, the joint has been taken apart for some reason and not remade properly.

In hard water areas, scaling of pipework can be a significant problem. Scale can loosen and fall into the system flow and cause knock on problems.

Insulation

Where asbestos is present, and it represents a health hazard, it should be removed taking precautions as required by the Health and Safety at Work Act.

Where it is concealed and/or does not present a health hazard, it should be left undisturbed until such time as replacement is essential.

Where leaks occur on insulated pipework, the wetting of the insulation causes the insulation value to decrease. This is a common occurence.

Damaged insulation covering or incompleted/ missing ends are also common. Where the covering is metal, this can leave sharp ends which are dangerous.

Valves

The most common problem with valves is that of leakage from glands which require tightening or replacing. This causes ugly staining of the surrounding pipework and insulation.

Debris or scale in pipework can be trapped in the seating or slides of an isolating valve preventing complete shut off. This problem can be dealt with by installing lever operated valves instead of the more usual wheel or lock shield versions. Scaling is noted as a particular problem with modern small bore radiator valves.

Useful life

If given adequate maintenance; pipework, fittings, insulation and valves can have extremely long lives.

Internal pipework (steel)	25–30 years
External pipework (steel, buried)	10–15 years
Internal pipework (copper)	25–30 years
Thermal insulation (internal)	25 years
Thermal insulation (external)	15 years
Thermal insulation (buried)	10 years
Valves (iron)	20 years
Valves (bronze)	25 years
Valves (glanded)	20 years
Valves (glandless)	25 years

B.5 SPACE HEATING APPARATUS

Usually consisting of either radiators or fan convectors, although in prefabricated/mobile classrooms there is extensive use of direct gas fired convector heaters.

Common faults

The most common fault with space heating apparatus is the build up of air. Air being an insulator, causes the heat output to reduce. On components where air collects, there should be vent cocks which should be periodically opened to allow the air to escape.

Leaks will occur on radiators towards the end of their useful life.

The principal fault on fan convectors occurs with filters which either become dusty or are not fitted. Filters can easily be cleaned and should always be fitted to prevent the accumulation of dust and debris on the heat exchanger fins (which reduces heat output).

After a significant period of time, motors on fan convectors can be expected to wear out and should be replaced.

Useful life

Radiators (cast iron)	25 years
Radiators (steel panel)	10–15 years
Fan convectors	15–20 years

B.6 CALORIFIERS/HEAT EXCHANGERS

Calorifiers/heat exchangers used in schools are mostly indirectly heated and manufactured from copper. In the future, smaller schools may be fitted with unvented water systems which should be fitted by certificated installers.

Common faults

The most common fault to be found on calorifiers/heat exchangers is that of leaks from joints.

Useful life

Calorifiers/heat exchangers	20 years

B.7 TANKS

Used for both feed and expansion and storage purposes, tanks are usually either galvanised sheet steel or polypropylene. Oil storage tanks are usually of welded mild steel construction.

Common faults

Leakage at joints

Corrosion in steel tanks which can break away and cause blockage

Leakage from ball float operated valves.

If insulation breaks away from tanks or from pipework surrounding tanks, freezing can occur in cold weather.

Useful life

Water tanks (steel)	15 years
Water tanks (non metallic)	30 years
Oil storage tanks	25 years

B.8 FANS

Fans on ventilation systems in schools may be used for local extract, toilet extract or kitchen extract purposes. There is also a requirement for extract ventilation in workshops in secondary schools from forges and machine tools. A range of fan types are in use including propeller, axial and mixed flow. Balanced supply and extract systems are rare in schools generally and consequently are not further considered.

Common faults

The most common faults with fans occur at the motors which may trip out or burn out. Tripping out implies either that the fan is operating with a motor fault, in which case the motor requires attention, or that the wrong overload trips have been installed.

Over a period of time, it is likely that bearings will wear and require renewing.

Usual life

Axial fans	15 years
Centrifugal/mixed flow fans	20 years
Propeller fans	10 years

B.9 KITCHEN EQUIPMENT

This will usually be supplied under a specialist sub-contract and should be under a maintenance arrangement with specialists.

Usual life

Industrial kitchen equipment	15 years
Domestic kitchen equipment	10 years

Training of contractors staff

In order to ensure that the maintenance work carried out in schools on behalf of the local authority is of sufficient quality, care should be exercised to ensure that the persons carrying out maintenance tasks have received adequate and acceptable training. This is particularly relevant in the case of control systems which may be complex and is a specialist area.

Where a maintenance contractor is employed, one or more of the following options are available:

- Named staff only should be used on local authority projects. The list of named staff should be updated annually.
- Evidence of the training which named staff have undertaken should be provided. This should indicate which components may be included for a particular member of staff and/or which excluded.
- Evidence of continuing training should be provided through the updating of the list of named staff.

Local authorities should maintain a register of acceptable maintenance training courses and their purpose. This list should be made available to contractors on request.

Appendix D

Routine inspection and maintenance by school personnel

This Appendix presents a range of inspection tasks which can be easily carried out by non-specialist school personnel. By carrying out these tasks on a regular basis, school personnel will be able to spot changes in the operational conditions of their mechanical services systems and bring them to the notice of local authority or maintenance engineers. The result of this can be that repairs are carried out before a problem becomes serious enough to require major work. In addition, since many maintenance tasks are related to energy use, highlighting necessary work may be regarded as contributing towards energy conservation.

Inspection tasks are presented in the form of checklists for daily, weekly and monthly inspections. The checklists are designed so that the work required should not intrude unduly on the time available to school personnel.

In addition to the inspection tasks outlined in this Appendix, more detailed technical checks and maintenance operations will be necessary at intervals. These should normally be the concern of the local authority or an appointed contractor according to predetermined maintenance schedules. The definition of these maintenance schedules should be carried out by the local authority. They are not included as part of this Appendix.

D.1 DAILY INSPECTION

1. In the boilerhouse/plant room:

a. Safety checks for: Oil leaks; Water leaks; Gas leaks

b. General checks for: Unusual noises

c. Control panels for: Indicator lamp failure; Panel door is closed and locked

d. Boiler plant for: Boilers are operating

e. Pumps for: Pumps are operating

f. Fans for: Fans are operating

NOTE: Close boilerhouse/plant room doors on leaving.

2. System checks

Whilst working around the school in the course of other duties, check for:

- Signs of water leakage from pipework, valves and heat emitters (radiators/convectors).
- Signs of damage to components.
- Positive shut off on taps.
- Ensure that all fan convector doors are closed and locked.

D.2 WEEKLY INSPECTION

1. In the boilerhouse/plant room:

a. Carry out all daily checks

b. General checks for: Satisfactory pressure and temperature gauge readings.

c. Control panels for: Correct status of selector switches.

No 'tripped', or 'failed' lights are showing

d. Boiler plant for: Leakage from burner seals onto boiler

Boiler casing secure.

e. Pumps for: Motors not overheating

f. Calorifiers for: Water leakage.

g. Fans for: Smooth running of fan with no excessive vibration.

Motors not overheating.

h. Timing devices for: Set at correct time.

i. Housekeeping & Safety: Ensure clear access to all plant items.

Remove to other storage such items as

ladders, desks etc.

Clean and tidy boilerhouse/plant room.

Ensure safety guards are secure.

2. System checks

Carry out all checks as would be done on a daily basis but as a specific inspection operation rather than in the normal course of duties.

D.3 MONTHLY INSPECTION AND OPERATIONS

1. In the boilerhouse/plant room:

a. Carry out all daily and weekly checks.

b. General checks for: Freedom of movement of pointers on pressure and temperature gauges

c. Control panels for: Clean panel front.

Check that all instrument covers are secure.

Change duty selection of duplicate plant to even wear.

Tighten any loose switches on panel front.

Warning: School personnel should not carry out any inspection or maintenance tasks inside the control panel.

d. Control equipment for: Correct control settings.

Check that thermostat responds to actual temperature change.

e. Boiler plant for: Combustion air ventilation grilles on pressure jet burners are clear of accumulation of dust.

Combustion air louvres into boilerhouse are clear of any blockage.

Leakage from flue joints.

Damage to flues/moisture seepage visible.

Signs of corrosion below the point where the flue joins onto the boiler.

f. Pumps and fans for: Drive belt wear (if drive belts fitted).

Drive belt tension.

Ensure correct alignment of pulleys

Check security of any anti-vibration mountings fitted.

g. Pipework for: Release air from all vent points.

Check operation of Automatic Air Vents.

Remove debris from dirt pockets and strainers.

Check pipe supports for security.

Check for corrosion at pipe joints.

Ensure that all insulation is securely fixed.

Check for signs of staining on insulation (sign of pipe leakage below).

Check bayonet connections and flexible hoses.

Appendix D

h.	Oil storage tanks for:	Check alarm operation. Ensure that there are no obstructions in the fill or vent pipe.
i.	Water storage:	Freedom and operation of float valves in expansion tanks. Vent and overflow pipe are not obstructed. Tank is not corroded. Insulation is securely fixed (including on cover). Lids are in place. Water level is approx. 150mm from bottom of F & E tanks.

2. System checks

a.	On fan convector: heaters	Remove internal filter and wash clean. Ensure that air inlet and outlet grilles are clear of obstruction and clean off accumulations of dirt. Release air from vent points. Check fins on heat exchanger for damage. Check operation of thermostat.
b.	On radiators:	Release air from vent points. Ensure security of fixing. Remove accumulations of dirt from between panels and/or sections.
c.	Thermostats:	Ensure that all covers are securely fixed
d.	Pipework:	Check for signs of corrosion.
e.	Valves:	Ensure freedom of movement of all valve mechanisms.
f.	Kitchens: Grease traps:	If blocked or dirty flush out with soda solution.
	Stoves, ovens,: boiling pans, etc	Test ignition device, check working thermostats, door seals for leakage, door closing mechanisms. Examine Safety Valves for correct operation.

D.4 TRAINING OF SCHOOL PERSONNEL

The intention of the above checklists is to highlight those operations which can be easily carried out by school personnel and which are within the range of their technical ability. It is appreciated however that the tasks outlined will be undertaken more willingly if the school personnel understand the reasons for the operations, the consequences of them not being carried out and, most particularly, the benefits available to the school as a whole by carrying them out.

It is therefore recommended that local authorities should establish schemes for training school personnel in the given inspection and maintenance operations. Such training need not be extensive since the checklists have been designed to include only activities which do not require extensive technical capability. It is probable that a short course would be sufficient. This should be reinforced with a training manual which mirrors the information given on the course.

It is recommended that course content should include the following.

a.	How to carry out inspections:	What to look for. Where to look for it. How to look for it.

b.	How to carry out simple maintenance operations:	What to do. How to do it. Safety precautions. Tools to use.

This item should include practical demonstrations. Local authorities might like to provide a recommended toolkit to school personnel as part of the course material.

c.	Reporting of problems:	What should be reported. When it should be reported. How to report it. To whom it should be reported.
d.	The relationship between school personnel inspection/ maintenance and local authority/ contractor maintenance	Technical benefit. Cost benefit.
e.	The consequence: of not maintaining	Breakdown. Failure School closure. Cost implications.
f.	The benefits of: maintenance	Reduced capital expenditures. Energy conservation. Safety.
g.	Operating considerations:	Normal operating temperatures for various outside conditions. Operating periods according to how the school is used. Avoidance of corrosion. Frost precautions. General safety matters.
h.	Fault tracing:	Use of fault tracing charts (see Appendix E).

Appendix E

Fault tracing

This Appendix provides some information on fault tracing, listing causes and possible remedies for a range of mechanical services components. Most of the actions and remedies shown on the fault tracing charts can be carried out by school personnel. Certain of the actions and remedies should only be undertaken by a specialist who has been properly trained on the installation, operation and maintenance of the component. Where specialist action is required, it is specifically highlighted on the fault tracing charts. (See Figures 7, 8 and 9.)

Item	Fault	Cause	Remedy
Boilers	Will not start	1. Electrical supply switched off	Ensure that boiler isolaters are switched on at local isolator panel isolator panel selector switch
		2. Incorrect time clock setting	Reset time clock
		3. Low water pressure condition (where pressure set fitted)	Ensure availability of water to pressurisation unit and check low pressure switch setting. Allow water pressure to rise.
		4. Lockout on boiler	SPECIALIST ACTION Reset high limit thermostat
		5. Motor fault on burner	SPECIALIST ACTION
		6. Burner will not ignite	SPECIALIST ACTION Check and service burner ensuring that electrodes are correctly set
	High flow temperature	1. Control thermostat setting too high	Reset thermostat to correct level
		2. Control/limit thermostat failure	SPECIALIST ACTION Replace thermostat
	Low flow temperature	1. Control thermostat setting too low	Reset thermostat to correct level
		2. Inadequate heat output from burner	SPECIALIST ACTION Check flame condition. Clean burner air intake. Adjust burner setting
	Flue gas leakage	1. Poor seal onto combustion chamber	SPECIALIST ACTION Renew gasket. Tighten securing nuts
		2. Poor seal from burner onto door	SPECIALIST ACTION Renew sealant. Tighten securing nuts
		3. Leaking flue connection	SPECIALIST ACTION Remake joint

Item	Fault	Cause	Remedy
Pumps	Not running	1. Incorrect time clock setting	Rest time clock
		2. Motor fault	SPECIALIST ACTION
	Will not start	1. Incorrect time clock setting	Reset time clock
		2. Switched off	Ensure the pump isolators are switched on at local isolator panel isolator panel on/off switch
		3. Motor fault	SPECIALIST ACTION
	Overloads tripping out	1. Wrong over-loads fitted	SPECIALIST ACTION Fit correct over-loads
		2. Motor fault	SPECIALIST ACTION
	Low duty	1. Pumping against high head	Ensure that isolating valves to pump are open
		2. System out of balance	SPECIALIST ACTION Check settings of regulating valves and rebalance if required
		3. Short circuit through standby pump	Close isolating valves to standby pump
		4, Pump speed low	SPECIALIST ACTION Readjust and/or renew seals and bearings. (Check speed and current consumed with normal operation figures)
		5. Pump faults	SPECIALIST ACTION Repair/replace

Appendix

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Item	Fault	Cause	Remedy
Controls	Required conditions not being maintained	1. Operation of local thermostats or pressure switches 2. Action of controller equipment 3. Controller settings 4. Operation of actuators 5. Linkages are slack or broken 6. Cleanliness of all operating mechanisms either locally or in panel 7. Operation of interlocks 8. Operation of coils in solenoid valves 9. Security of connections 10. Availability of electrical supply	SPECIALIST ACTION Control systems are extremely complex and the remedying of any faults on the systems should not be undertaken by anyone who is not thoroughly familiar with the types of controls installed

Item	Fault	Cause	Remedy
Fan Convectors	Insufficient heat output	1. Clogged filter	Remove filter, clean and replace
		2. Dirt accumulation on battery	Clean heater battery
		3. Air in battery	Vent heater battery
		4. Insufficient water flow	SPECIALIST ACTION Check what the regulating valve setting should be and reset to the correct level
		5. Incorrect thermostat setting	Reset to the correct level
		6. Low water temperature	Check boiler, pumps
		7. Faulty speed change thermostat	SPECIALIST ACTION Replace
		8. Motor failure	SPECIALIST ACTION
	Too much heat	1. Filter not replaced after maintenance	Replace
		2. Too much water flow	SPECIALIST ACTION Check what the regulating valve setting should be and reset to the correct level
		3. Incorrect thermostat setting	Reset to the correct level
		4. Faulty speed change thermostat	SPECIALIST ACTION Replace
	Will not start	1. Electrical supply switched off	Ensure that local isolator is switched to the 'on' position
		2. Held off by low temperature cut-out thermostat	Check flow temperature is above the required level

Item	Fault	Cause	Remedy
Calorifier	High water temperature	1. Thermostat setting too high	Lower setting to correct level
		2. Control malfunction	SPECIALIST ACTION See control's chart
	Low water temperature	1. Thermostat setting too low	Raise setting to correct level
		2. Incorrect setting on valves serving calorifier	SPECIALIST ACTION Check what the valve settings should be and reset accordingly
		3. Insufficient water flow to the calorifier	Check pump operation. See 'pumps' chart
		4. Control malfunction	SPECIALIST ACTION See control's chart
Oil transfer system	No oil flow to burner	1. Isolating valve closed	Open valve
		2. No oil in tank	Arrange for urgent delivery from supplier
		3. Drop weight fire valve closed	i. Check fusible link. If it is broken it indicates a dangerous boiler condition which could cause fire. Check boiler thoroughly ii. Check and reset panic button if it has been operated iii. Check and ensure that tension wire is not slack or broken. Tighten bottle screw or replace if necessary iv. Check security of keepers and that they are not pulled out of wall. Refix if necessary
		4. Transfer pump (where fitted) inoperative	See pump fault chart
	Insufficient oil to burner	1. Partially closed	Fully open valve
		2. Blocked atomiser jet	SPECIALIST ACTION Service burner

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Item	Fault	Cause	Remedy
Oil transfer system (cont'd)	Oil burner inoperative	1. Burner switched off at local isolator	Switch on at local isolator
		2. Burner fault	SPECIALIST ACTION Repair/replace
	Incomplete burning of fuel (presence of carbon monoxide in flue gases)	1. Insufficient air for combustion	i. Check burner air intake for blockage and ensure free air flow ii. Check and ensure that there is sufficient air available to freely enter boiler compartment, and that air inlet points are not blocked
		2. Burner fault	SPECIALIST ACTION Repair/replace
	Oil contents gauge	1. Gauge fault	SPECIALIST ACTION Repair/replace as required
		2. Fault on transmission line to gauge	SPECIALIST ACTION i Check line for blockage or break if capillary or bourdon tube used, or if hydraulic. Repair/replace as required ii. If electric system. Check security of terminals and ensure tightness. Ensure electrical supply available. Ensure line not broken.

Item	Fault	Cause	Remedy
Fan	Not running	1. Incorrect timing device setting	Reset timing device
		2. Motor fault	SPECIALIST ACTION
	Will not start	1. Switched off	Ensure that fan isolators are switched on at local isolator panel isolator panel on/off switch
		2. Incorrect timing device setting	Reset timing device
		3. Motor fault	SPECIALIST ACTION
	Overloads tripping out	1. Motor fault	SPECIALIST ACTION
		2. Wrong overloads fitted	SPECIALIST ACTION Fit correct overloads
	Delivering too much air	1. Low system resistance	Check settings of dampers
		2. Fan speed too high	SPECIALIST ACTION Belt driven fan (centrifugal/mixed flow). Check speed of rotation. Fit correct pulleys for duty (larger fan pulley, smaller motor pulley or both)
		3. Blade pitch angle incorrect	SPECIALIST ACTION Reset blades to correct pitch angle
	Not delivering enough air	1. High system resistance	Check settings of dampers
		2. Drive belts slipping	SPECIALIST ACTION Check rotation speed of fan and motor and adjust belt tension to the correct level
		3. Fan running backwards 3-phase electrical supply	SPECIALIST ACTION Swap over wiring connections at terminal of any two phases
		4. Blade pitch angle incorrect	SPECIALIST ACTION Reset blades to correct pitch angle
		5. Restriction at fan inlet or outlet	Check visually and if present remove restrictions

Item	Fault	Cause	Remedy
Fan (cont'd)	Vibration	1. Worn, broken or loose anti-vibration mounting	SPECIALIST ACTION Renew or tighten as required
		2. Holding bolts loose	Tighten as required
		3. Fan out of balance	SPECIALIST ACTION Disconnect fan from drive and rotate impeller. If fan is unbalanced it will continually come to rest in the same position.
		4. Worn bearings on shaft or impeller	SPECIALIST ACTION Check play on bearings and renew as required
		5. Bent impeller shaft	SPECIALIST ACTION Replace
		6. Motor out of balance	SPECIALIST ACTION Rebalance
	Noise	1. Drive belt tension incorrect	Reset belts to correct tension
		2. Fan/motor pulleys out of alignment	Adjust as required
		3. Worn bearings	SPECIALIST ACTION Check play on bearings and renew as required
		4. Blade pitch angle incorrect	SPECIALIST ACTION Reset blades to correct pitch angle
		5. Impeller impinging on fan scroll/casing	SPECIALIST ACTION Disconnect device and check, rotation manually. A temporary repair can then be carried out, but the balance of the fan should be checked.

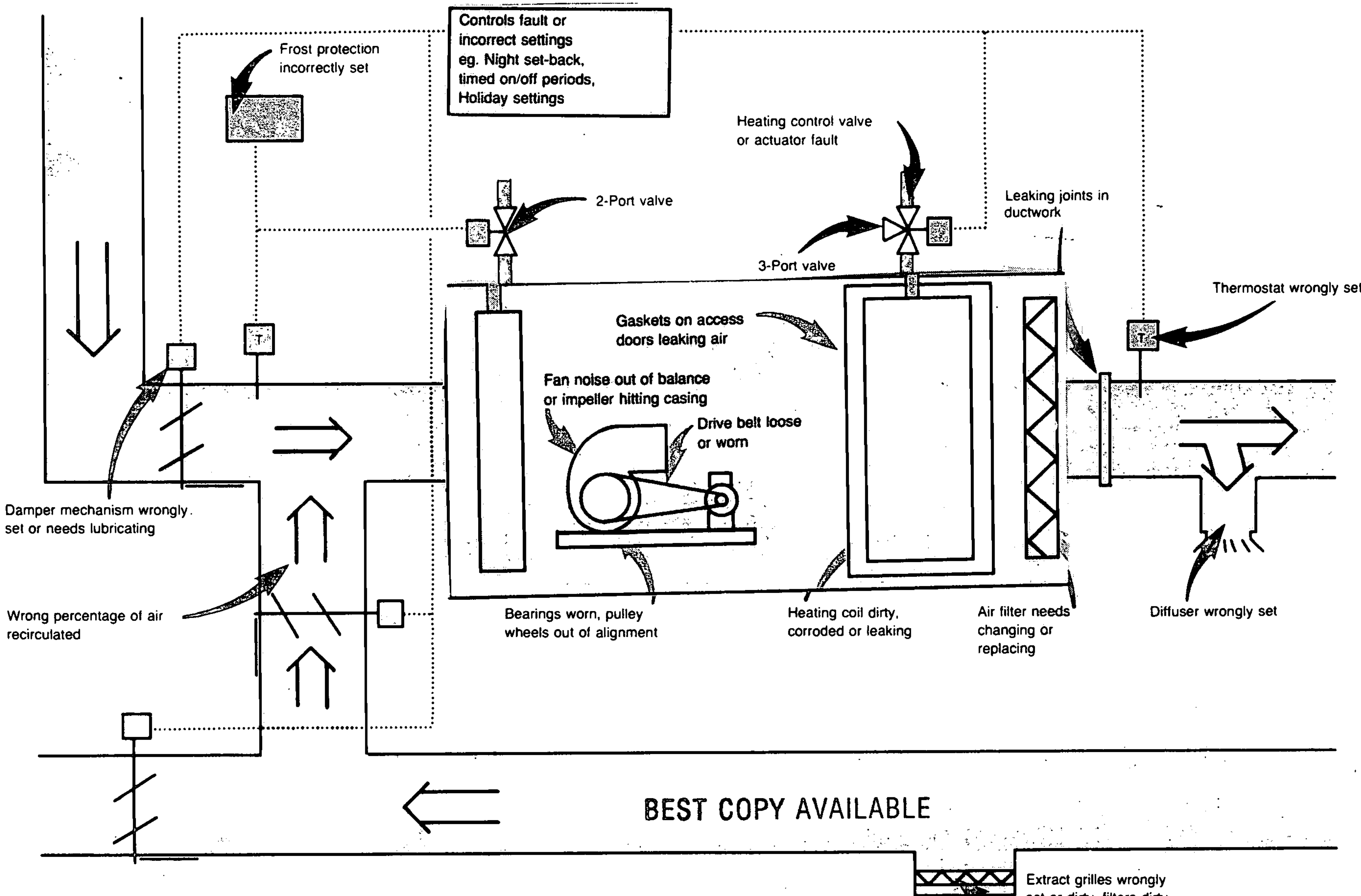

Figure 7: Typical maintenance problems on ventilation systems

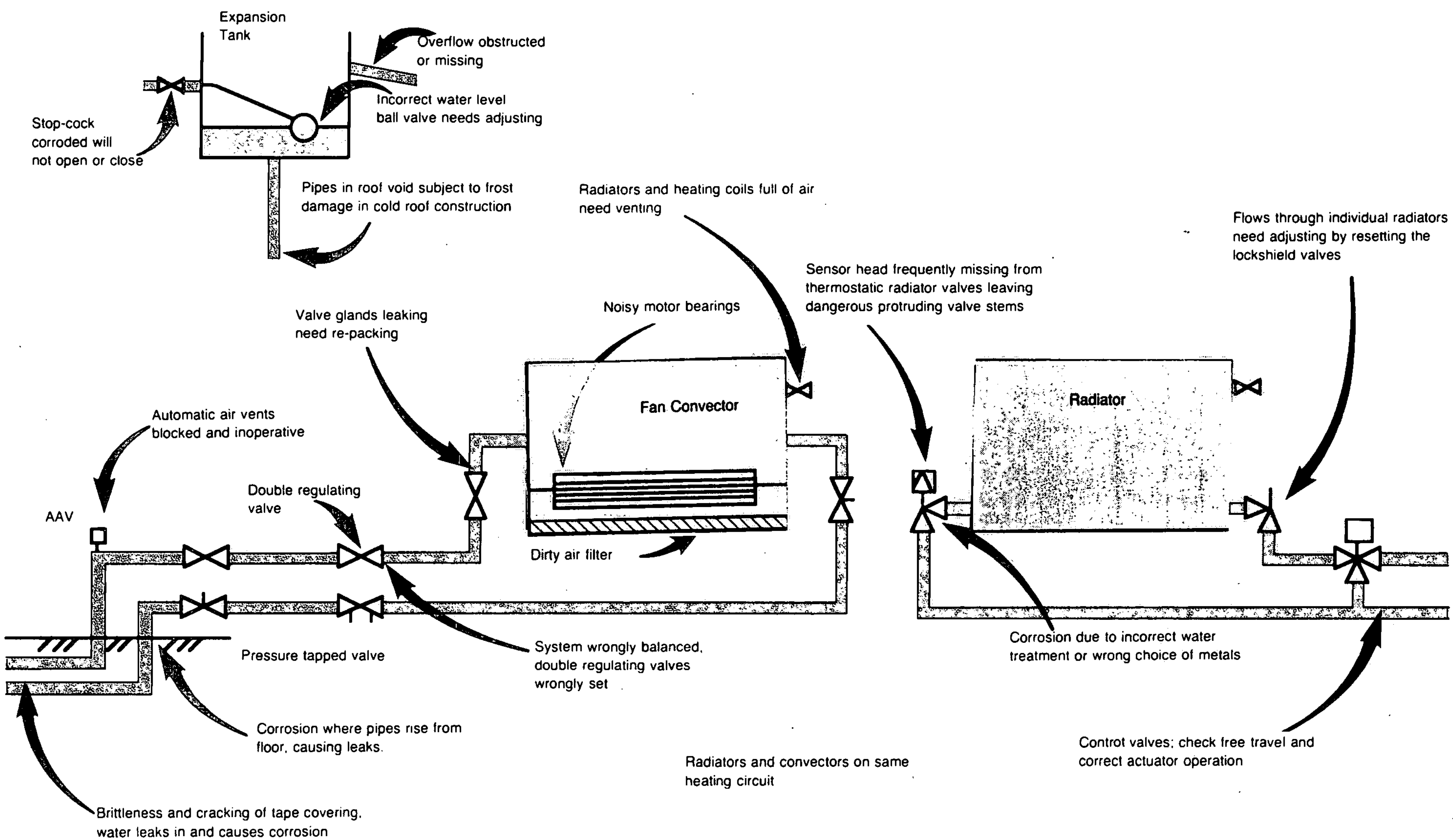

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Figure 8: Typical maintenance problems on heating circuits

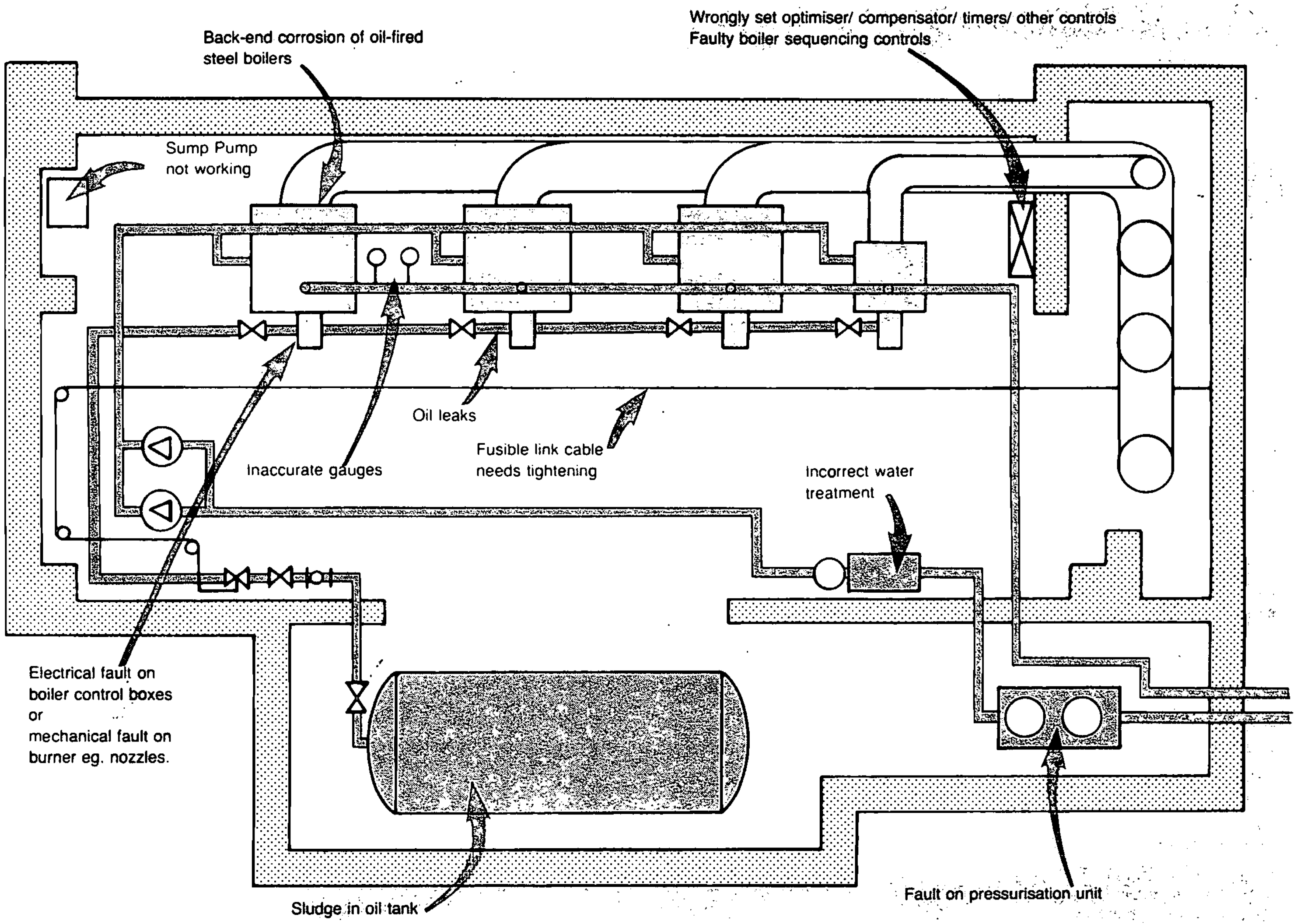

Figure 9: Typical maintenance problems in oil fired boilerhouses

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Appendix F

Operating and maintenance manuals

Operating and maintenance manuals are a valuable source of information both to the operator of the engineering services installation and to the person or firm carrying out the required maintenance. In many cases, the manuals provided consist exclusively of the literature provided by equipment suppliers without any supporting information regarding the context of how the equipment is to be used, design or commissioning parameters or safety information, fault finding procedures or the like. Such manuals are inadequate.

It is recognised that operating and maintenance manuals may be prepared in varying degrees of detail depending on the size and complexity of an installation. Given the nature of typical installations within educational premises and the fact that operating personnel are rarely trained in building services, it is considered that 2 manuals are required; a user manual and a maintenance manual.

The user manual should be made available for local use at the school. The maintenance manual should be made available only to the local authority or its appointed maintenance contractor. It should not be available on site.

Material contained within the user manual may be repeated as part of the maintenance manual.

The user manual and maintenance manual can be used to provide the following benefits.

- As a basis for correct and efficient plant operation
- As an information base for effective maintenance
- As a comprehensive source of reference
- To create safety awareness
- To maximise plant utilisation and life
- As a basis for staff training
- To list emergency procedures
- As a reference for use in future modifications

F.1 CONTENTS

Although the degree of detail may vary according to the size and complexity of an installation, the following information should always be included in the user manual in the given sequence:

How to use the manual

A brief guide to the contents, layout and structure of the manual to enable the reader to comprehend the scope and structure.

Installation Records

- The name and address of the installation.
- Ownership details.
- Name and address of the designer, installation contractor and relevant associated sub-contractors.
- Date of completion of the installation (or certificate of practical completion) and details of the defects liability period.
- Insurance inspection certificates.
- Safety and fire certificates.
- A statement on hazards known to exist and safety precautions to be adopted.

Purpose of the installation

A summary overview of the original design intent for the systems installed giving:

- Parameters and conditions within which it has been designed to operate.
- Type of services required to operate the system (gas, water, electricity etc.)
- Means of control.

Description of the Installation

For each system:

- System type
- System location and what it serves.
- What the system depends upon in order to function

Design data

Equipment schedule

Type, model, serial number and manufacturer/ supplier of all equipment items.

Operation of plant

Instructions for the safe and efficient operation of systems under both normal and emergency conditions additional to those provided in manufacturers' literature and including:

- Procedures for starting up, shutting down and running under both normal and emergency conditions.
- The recommended strategy for operation and control.
- Control data (location and set points of control elements).
- Interlocks between plant items.
- Safety precautions.

Maintenance

For each item of plant and equipment, detail the manufacturers' recommendations and instructions for maintenance. This will typically be in the form of manufacturers' literature. Also identify:

- Means of isolation and return to service.
- The nature of deterioration and the defects to be looked for.

Inspection and maintenance tasks which may be carried out by school personnel should be specifically identified (see Appendix D).

Fault finding

Indicate procedures for the logical diagnosis and correction of faults by school personnel (see Appendix E).

Index of plans and drawings

Include all record drawings with the user manual together with all drawings issued by manufacturers. Provide an index to all drawings including details of source and title.

Emergency information

Emergency information should be easily located in the manual, preferably at the back and should include names, addresses, telephone and telex/FAX numbers of appropriate contacts in the event of fire, theft, burglary or leakage/failure of gas, electricity or water.

- Indicate the location of safety equipment.
- Give procedures for rendering installations safe.

F.2 CONTENTS OF THE MAINTENANCE MANUAL

Although the degree of detail may vary according to the size and complexity of an installation, the following information should always be included in the maintenance manual in the given sequence.

How to use the manual

A brief guide to the contents, layout and structure of the manual to enable the reader to comprehend the scope and structure.

Installation records

Information as included in the user manual together with the following additional information:

- Details of local and public authority consents.
- All guarantees affecting the installation together with their expiry dates and including contact points for execution of guarantees.
- Test certificates.

Purpose of the installation

A detailed overview of the original design intent and a summary for each engineering system giving:

- Parameters and conditions within which it has been designed to operate.
- Type of services required to operate the system (gas, water, electricity etc.)
- Intended means of control and control actions.

It should be noted that the purpose of installation section, within the maintenance manual, should be a much more expanded insight into the design intent than that included in the user manual.

Description of the installation

Information as included in the user manual together with the following additional information:

- Anticipated economic life (of system and equipment).
- Planned operational efficiency.

Equipment schedule

Type, model, serial number and manufacturer/supplier of all equipment items (as in the user manual) together with the following additional information.

- Parts identification and spares list

The maintenance manual should also identify all replaceable assemblies, sub-assemblies and components within larger equipment items together with providing lists of spares which are recommended to be held.

Operation of plant

Information as included in the user manual together with the following additional information.

- Control data (purpose, control sequence, limits of capability and control mode of control elements).

Maintenance

Information as included in the user manual together with the following additional information:

- Adjustments, calibration and testing.
- Special tools and test equipment which may be required.

Identify maintenance which should be carried out on a periodic basis for preventive purposes. Schedule the following:

- Inspections to be carried out by school personnel (see Appendix D).
- Inspections and examinations to be carried out by others.
  - Tests
  - Adjustments
  - Calibration
  - Lubrication
  - Overhaul

In the case of educational premises, the party responsible for carrying out the periodic activity for each item of plant or equipment should be specifically identified.

Fault finding

Indicate procedures for the logical diagnosis and correction of faults. Refer to BSRIA Technical Note TN 12/86 'Fault finding procedures for building services'.

Include also the fault finding procedures by school personnel as a reference (see Appendix E).

Lubrication

Schedule all plant and equipment items requiring lubrication together with the type of lubricant and the method and frequency of application.

Index of plans and drawings

Information as included in the user manual.

Emergency information

Information as included in the user manual.

F.3 PROVISION OF OPERATING AND MAINTENANCE MANUALS

At present, the usual source for the provision of operating and maintenance manuals is the installation contractor. The main reason for this is that it is the installation contractor who has the greatest number of appropriate contacts.

The recommendations for user and maintenance manuals above also cover the provision of information concerning the actual design and the parameters utilised to achieve the design intent. A strong case can therefore be made for the designer to prepare the manuals.

A third possibility is that of utilising a company specialising in the production of manuals. It is considered however, that the extent of systems within typical educational premises would cause this to be uneconomic.

F.4 COST OF MANUAL

The average cost throughout projects of all types for the production of operating and maintenance manuals is between 0.3% and 0.5% of installation cost. For a small project, such as a primary school, this could rise to between 1% and 2%. Even at this level, the cost of production may be easily justified by the long term savings available from the provision of good information.

As a percentage of the installation, the cost of producing both a user manual and a maintenance manual may be slightly higher than for a single operating and maintenance manual even though the content of one is only a subset of the content of the other.

F.5 OBTAINING MANUALS

A frequent experience is that manuals are not available until after completion when they should in fact be available at completion. A method of ensuring that they are available may be to include their preparation as a prime cost sum in the tender which can, if necessary, be expended elsewhere by the client.

Appendix G

Maintainability

G.1 MAINTAINABILITY

Maintainability is defined as the characteristic of design and installation indicating the measure of ease and rapidity with which components and systems can be retained at a specific level of performance.

The important aspects of maintainability are that both the design and the installation should pay due regard to the fact that maintenance work will have to be carried out when the mechanical services systems become operational. Lack of attention to the requirement for maintenance during design and installation will inevitably make it more difficult and consequently increase its cost.

Comparison of recorded data over a period of time will determine whether or not a system and components are becoming more maintainable.

G.2 RELIABILITY

Reliability may be defined as the probability that a component or system will perform its intended function for a specified period under stated conditions. The achievement of a high level of reliability can prove to be of significant benefit in reducing the amount of maintenance required, as well as its cost, and in extending the life of systems and components to the maximum economic length.

Many organisations in industry practice reliability programmes and have found that the cost of carrying them out can be more than offset by the reduction in maintenance costs. In mechanical services installations generally however, reliability of systems and components is not usually a factor taken into consideration and the information required to enable such a programme is not easily available.

Reliability is not achieved by accident. It requires thought about the systems and components concerned, their design, the quality of installation, commissioning, the extent of maintenance and its quality.

There are two types of reliability to be considered in respect of the systems and components and these are respectively 'inherent reliability' and 'achieved reliability'

G.2.1 Inherent reliability

This is the level of reliability built into the design of a system or component and is that which would have been possible if every system/component were to perform precisely to the designers' intention.

G.2.2 Achieved reliability

This is the level of reliability which may be expected to be achieved as a result of a comprehensive maintenance programme. Achieved reliability can only be as good as the inherent reliability designed into a system; thus if a system is not inherently reliable, then no amount of maintenance can realistically achieve reliability.

G.3 MAINTAINABLE SYSTEM

The factors which lead to maintainable systems are largely determined by good practice at the design, installation and commissioning stages.

Design Considerations

- Ensure that configuration of the system is technically sound and conforms to good practice, eg:
  - Relative positions of pumps, vents and feeds.
  - Location of isolating valves to allow section closure.
  - Indications of pump motor alignment.
- Ensure that access space is allowed to components to be maintained.
- Ensure that sufficient space for maintenance is allowed around components to be maintained.
- Ensure that drain points are allowed at low points in systems and that they are included in each section which may be individually closed.
- Allow standby plant where its operation is critical to the function of the system.
- Design components to operate at or below their maximum duty point.

- Use materials and components of an appropriate quality.
- Use components whose access time for maintenance is minimised e.g. wing nuts on all access panels can be removed and replaced more easily and quickly than fixed nuts.
- Ensure that components in a system are aligned to facilitate maintenance e.g. valves in ceiling space located adjacent to access panel and with hand wheels pointing down.

Installation considerations

- Cover open ends of components and materials during storage to prevent ingress of dirt.
- Ensure that materials and components installed are of an appropriate quality.
- Adhere to manufacturers' fixing recommendations.
- Ensure that joints are made with tube and fittings which have been deburred prior to installation.
- Ensure that joints are properly cleaned and made, removing any excess jointing material afterwards.
- Ensure that all fixings are correctly positioned and secure.

Commissioning considerations

- Ensure that all required data are available prior to commencement.
- Ensure that systems are flushed to remove debris.
- Provide records of all commissioning checks.

Maintenance

- Maintenance is concerned with achieving and maintaining reliability. This cannot be done unless a maintenance programme is operated. Therefore a preventive maintenance programme should be set up.
- Maintenance should be carried out in accordance with the operating and maintenance instruction manuals.
- Other than carrying out maintenance at prescribed intervals, the condition of systems and components should be assessed periodically in accordance with a defined condition appraisal plan. This is particularly important with systems and components which may be approaching the end of their normal working life.
- The quality of maintenance work carried out either by direct labour or by contractors should be subsequently checked. It is appreciated that not every item of work may be checked in detail so consequently, a sampling procedure should be established.
- The reliability of systems and components together with the cost of maintenance should be recorded particularly where a positive programme for measuring reliability has been set into operation. This will enable the assessment of the cost benefit of maintenance work and increased reliability.

The bath tub curve

The bath tub curve (Figure 10) is frequently quoted as a model which describes the likelihood of the instantaneous failure of a system over its whole life. It gets its name from its typical shape which resembles that of a bath tub and plots the likelihood of failure (failure rate) against time.

The applicability of the bath tub curve is confined to systems which are maintained. There is doubt regarding whether it can be applied to non maintained systems. There is also some doubt as to whether it can be strictly applied to individual components (BS5760:part 2:1981).

The bath tub curve consists of three phases each of which is described by a particular characteristic of failure rate.

- Poor design
- Operator error
- Maintenance error.

The rate of failure decreases over time as the various factors causing the high failure rate are addressed:

- Design faults and installation errors are addressed (the majority of these can be dealt with during the defects liability period of a project).
- Poor components are replaced on failure.
- Operators and maintainers learn from early experience.

Mathematically, the form of the curve in phase 1 can be described as a hyper-exponential distribution or a Weibull distribution with a curve shape factor of less than 1.

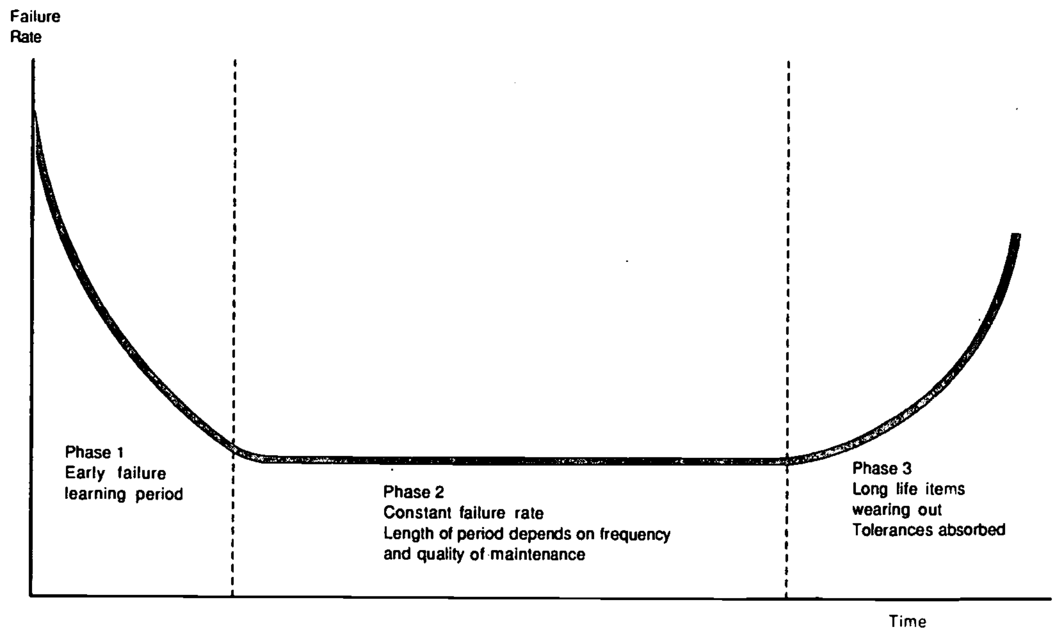

Figure 10: The bath tub curve

H.1 Phase 1: DECREASING FAILURE RATE

This phase occurs when the system is new. The gradient of the curve in phase 1 is accentuated if the design is also new and untried. There are a number of reasons why the rate of failure is higher in a new system:

- Installation error
- Poor quality of component parts
- Manufacturing faults

H.2 Phase 2: CONSTANT FAILURE RATE

In maintained systems, after the early failure period, the system will have settled down and the failure rate of items within the system can be expected to become fairly constant. During this phase, failure may occur due to independent, random causes which cannot be predicted.

Again, this applies only to maintained systems since, in a non maintained system, failure will occur for predictable, non random reasons.

Mathematically, the form of the curve in phase 2 can be described as a Weibull distribution with a curve shape factor equal to 1.

H.3 Phase 3: INCREASING FAILURE RATE

During this phase, system components with a long life will be wearing out and the instantaneous failure rate can be expected to increase with time.

Mathematically, the form of the curve in phase 3 can be described as a Weibull distribution with a curve shape factor greater than 1.

H.4 FACTORS AFFECTING THE BATH TUB CURVE

In a maintained system the shape of the curve can be affected by the maintenance policy adopted. This is particularly relevant to phase 2 where the failure rate is expected to be fairly constant. The rate of failure is sensitive to the frequency and quality of the maintenance carried out as also is the length of time over which phase 2 can be considered as the dominant failure mode.

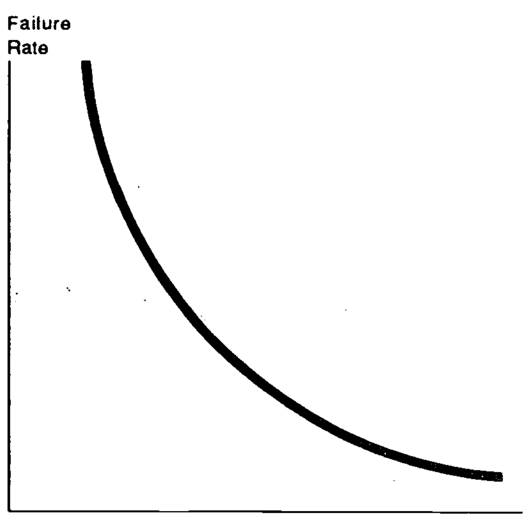

Figure 11: Failure rate against maintenance cost

A limiting case on the failure rate within phase 2 is apparent when the maintenance policy adopted is to replace components only when they actually fail. In this case, the rate of failure will be higher and the duration of phase 2 shorter than with a policy of planned maintenance.

Preventive maintenance will cause a lower failure rate.

The law of diminishing returns (Figure 11) applies however whereby a point will occur when the increased effort and cost put into preventing failure will result in an unacceptably low reduction in failure rate.

The causes of failure in phase 1 can often be limited with careful thought prior to setting the system into operation. The curve cannot be completely flattened out to the extent of that in phase 2, but the gradient can be reduced by attention to the following:

- Ensuring that the quality of components used is adequate.
- Correctly specifying the duty of components.
- Ensuring that commissioning is properly carried out.
- Providing proper training in system operation to those responsible for maintaining the system.

Appendix I

Life cycle costing

I.1 LIFE CYCLE COSTING — PURPOSE

1. The purpose of life cycle costing is to assess the effect of all variables which may be affected by an action. In the case of an action to replace an item of plant or a system, the following are the variables which should be considered:

Capital cost of replacement	(C)
Energy cost	(E)
Maintenance cost	(M)
Repairs/replacement of parts	(R)
Scrap value of existing item	(S)

2. To determine the life cycle cost of an action, it is necessary to know the period of time over which the costs are to be analysed. For instance, it may be that comparative life cycle costs over a 5 year period are required to assess whether a replacement action is cost effective or not. The period of time to be considered is denoted by the letter (N).

3. For a valid economic comparison to be made, all cost must be adjusted to represent a present value. Present value works on the assumption that a given amount of money is worth more today than in future. By adjusting the value of money to a present value, the opportunity costs associated with either carrying out or delaying an action may be assessed. The adjustment to give present value is termed discounting, and a discount factor is included in the life cycle cost calculations. The discount factor is denoted by the letter (d). For the public sector the current discount factor is 6% and is under review.

4. Assessment of life cycle costs is undertaken over the period (N) years and is the summation of the costs over that period. Therefore, the actual cost is calculated for each year up to N and the year in question is denoted by the letter (j). Thus costs are assessed for the first year (j=1), the second year (j=2) and so on up to the Nth year (j=N).

5. In order to differentiate between the costs of carrying out an action and not carrying out an action, tables are prepared showing costs in a particular year. These can then be added together to give a present value. Differentiation is achieved by indicating costs of carrying out an action by placing a bar over the symbol (for instance, energy costs would be $\bar{E}$) whilst not carrying out an action is left as the actual denoting letter (for instance, energy costs would be E). Present values are denoted by the subscript (p).

6. Thus, the life cycle energy cost difference at present value is

$$(\bar{E}_p - E_p)$$

7. A similar assessment of cost difference applies to each of the variable costs given above.

I.2 DETERMINING PRESENT VALUE

1. The present value of a particular variable can be assessed using a simple equation which is similar in every case. If we consider energy cost the equation takes the following general form

$$\bar{E}_p = \sum_{j=1}^{j=N} \frac{(\bar{E}_j)}{(1+d)^j}$$

2. This equation can be expanded to show how costs can be calculated over a period of time (N). To do so subscripts are used to indicate which year is being dealt with (1, 2, —,N)

$$\bar{E}_p = \frac{\bar{E}_1}{(1+d)^1} + \frac{\bar{E}_2}{(1+d)^2} + \text{———} + \frac{\bar{E}_N}{(1+d)^N}$$

3. If a period of 5 years is considered (N=5), then the complete arithmetical calculation is:

$$\bar{E}_p = \frac{\bar{E}_1}{(1+d)^1} + \frac{\bar{E}_2}{(1+d)^2} + \frac{\bar{E}_3}{(1+d)^3} + \frac{\bar{E}_4}{(1+d)^4} + \frac{\bar{E}_5}{(1+d)^5}$$

Note that the same analysis applies to other variables.

Maintenance Cost : Use $\bar{M}_p$ instead of $\bar{E}_p$

Repairs/replacement : Use $\bar{R}_p$ instead of $\bar{E}_p$ of parts.

I.3 CAPITAL COSTS

1. Capital cost appears only once in the life cycle cost analysis at the time of occurrence. If that occurrence is immediate then the value of (j) is 0 and only the actual present cost appears in the calculation. This can be proven as follows:

$$\bar{C}_p = \frac{\bar{C}_0}{(1+d)^0}$$

2. Since the value of any number raised to the power 0 is always 1 then $\bar{C}_p = \bar{C}_o$, the actual capital cost at the time of occurrence.

I.4 SCRAP VALUE

1. In a similar manner to capital costs, the scrap value of an item to be replaced occurs only once in a life cycle cost calculation. When this is at the end of the period in question after a time of (N) years the calculation for scrap value is:

$$\bar{S}_p = \frac{\bar{S}_N}{(1 + d)^N}$$

I.5 CALCULATION OF LIFE CYCLE COST

1. The present value of life cycle costs is found by adding together the cost of all the variables analysed. It should be noted that, in this calculation, the scrap value of an item is taken as being a benefit to the owner and is thus indicated as being a negative number so that it lowers the total life cycle cost. Please see Tables 4 and 5 for more information on calculating life cycle cost.

2. If the life cycle cost is denoted by LCC, then the costs of undertaking an action are:

$$\overline{LCC} = \bar{C}_p + \bar{E}_p + \bar{M}_p + \bar{R}_p - \bar{S}_p.$$

3. The costs of not undertaking an action are:

$$LCC = C_p + E_p + M_p + R_p - S_p.$$

4. To determine whether an action should be taken, the life cycle costs of undertaking it should be compared with the life cycle costs of not undertaking it. If the cost of undertaking is lower than the cost of not undertaking, then it is economic to do the work.

Compare $\overline{LCC}$ with LCC; $(\overline{LCC} - LCC)$

If $(\overline{LCC} - LCC)$ is less than 0, i.e. a negative number, then undertake the work.

I.6 REPAIR/REPLACEMENT COST

1. It should be noted that the repair/replacement costs used in the life cycle cost analysis are those which continually recur. They are different to capital costs. Thus if a 'widget' on a piece of plant needs to be replaced twice every year, this is the repair/replacement cost used in this part of the analysis.

I.7 DEFERRED WORK

1. The above analysis assumes that a project is to be undertaken immediately. The analysis however can equally well be undertaken for work which is to be deferred until sometime in the future. In this case, the starting value for (j) is different and is equal to the (m+1)th year where (m) is the value assigned to the period of deferment.

2. The calculation of variables is still carried out at present value, but the equations are of the form as follows.

Capital cost: $$\bar{C}_p = \frac{\bar{C}_m}{(1 + d)^m}$$

Energy cost: $$\bar{E}p = \sum_{j=m+1}^{N} \frac{\bar{E}_j}{(1+d)^j}$$

Maintenance cost: $$\bar{M}p = \sum_{j=m+1}^{N} \frac{\bar{M}_j}{(1+d)^j}$$

Repair cost: $$\bar{R}p = \sum_{j=m+1}^{N} \frac{\bar{R}_j}{(1+d)^j}$$

3. Taking energy cost as an example. If the replacement action is deferred until 2 years from now and the life cycle is considered as being over 5 years, then the energy costs start from the 3rd year (m = 2).

Thus:

$$\bar{E}_p = \frac{\bar{E}_3}{(1 + d)^3} + \frac{\bar{E}_4}{(1 + d)^4} + \frac{\bar{E}_5}{(1 + d)^5} + \frac{\bar{E}_6}{(1 + d)^6} + \frac{\bar{E}_7}{(1 + d)^7}$$

Capital cost is $$\bar{C}_p = \frac{\bar{C}_2}{(1 + d)^2}$$

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Description Year	Year 0	Year 1	Year 2	Year 3	——	Year N	Total For Variable
Capital costs ($\tilde{C}_p$)	$\tilde{C}_0$	–	–	–	–	–	Sum all capital costs
Energy cost ($\tilde{E}_p$)	$\tilde{E}_0$	$\frac{\tilde{E}_1}{(1+d)^1}$	$\frac{\tilde{E}_2}{(1+d)^2}$	$\frac{\tilde{E}_3}{(1+d)^3}$	———	$\frac{\tilde{E}_N}{(1+d)^N}$	Sum all energy costs
Maintenance ($\tilde{M}_p$) cost	$\tilde{M}_0$	$\frac{\tilde{M}_1}{(1+d)^1}$	$\frac{\tilde{M}_2}{(1+d)^2}$	$\frac{\tilde{M}_3}{(1+d)^3}$	———	$\frac{\tilde{M}_N}{(1+d)^N}$	Sum all maintenance costs
Repair/replacement ($\tilde{R}_p$)	$\tilde{R}_0$	$\frac{\tilde{R}_1}{(1+d)^1}$	$\frac{\tilde{R}_2}{(1+d)^2}$	$\frac{\tilde{R}_3}{(1+d)^3}$	———	$\frac{\tilde{R}_N}{(1+d)^N}$	Sum all repair/replacement costs
Scrap value ($\tilde{S}_p$)	$-\tilde{S}_0$	–	–	–	–	–	Sum all scrap value
Description TOTAL FOR YEAR	Sum all year 0 costs	Sum all year 1 costs	Sum all year 2 costs	Sum all year 3 costs	–	Sum all year N costs	TOTAL FOR ALL YEARS OR TOTAL FOR ALL VARIABLES

Table 4: Calculation of life cycle cost if action *is* taken **Value = $\widetilde{LCC}$**

Description Year	Year 0	Year 1	Year 2	Year 3	——	Year N	Total For Variable
Capital costs (C_p)	C_0	–	–	–	–	–	Sum all capital costs
Energy cost (E_p)	E_0	$\frac{E_1}{(1+d)^1}$	$\frac{E_2}{(1+d)^2}$	$\frac{E_3}{(1+d)^3}$	———	$\frac{E_N}{(1+d)^N}$	Sum all energy costs
Maintenance (M_p) cost	M_0	$\frac{M_1}{(1+d)^1}$	$\frac{M_2}{(1+d)^2}$	$\frac{M_3}{(1+d)^3}$	———	$\frac{M_N}{(1+d)^N}$	Sum all maintenance costs
Repair/replacement (R_p)	R_0	$\frac{R_1}{(1+d)^1}$	$\frac{R_2}{(1+d)^2}$	$\frac{R_3}{(1+d)^3}$	———	$\frac{R_N}{(1+d)^N}$	Sum all repair/replacement costs
Scrap value (S_p)	–	–	–	–	–	$\frac{-S_N}{(1+D)^N}$	Sum all scrap value
Description TOTAL FOR YEAR	Sum all year 0 costs	Sum all year 1 costs	Sum all year 2 costs	Sum all year 3 costs	–	Sum all year N costs	TOTAL FOR ALL YEARS OR TOTAL FOR ALL VARIABLES

Table 5: Calculation of life cycle cost if action *is not* taken **Value = LCC**

I.8 ANALYSIS OF LIFE CYCLE COSTS USING A COMPUTER SPREADSHEET

1. The preparation of a life cycle cost analysis using the tables shown can be greatly eased by using a computer. The tabular nature of the calculation makes it particularly easy to use a general purpose spreadsheet program. Net present value calculations are available in many spreadsheet mathematical and business software packages which use an NPV function, thereby reducing the calculation to a single step.

2. Tables 6 and 7 provide an example of the output obtained from a spreadsheet life cycle cost analysis.

Based on: Discount factor d – .05
Capital cost C – 2100
Scrap value – 50

Description		Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Total for Variable
Capital costs	$\bar{C}_p$	2100						2100
Energy cost	$\bar{E}$	1000	1000	1000	1000	1000	1000	
	$\bar{E}_p$	1000	952	907	864	823	784	5330
Maintenance cost	$\bar{M}$	120	120	120	120	120	120	
	$\bar{M}_p$	120	114	109	104	99	94	640
Repair/replacement cost	$\bar{R}$	0	0	50	0	50	0	
	$\bar{R}_p$	0	0	45	0	41	0	86
Scrap value	$(\bar{S}_p)$	–50					0	–50
Total for Year (Present value)		3170	1066	1061	968	963	878	8106
Running Total		3170	4236	5297	6265	7228	8106	

Table 6: Spreadsheet example of calculation of life cycle cost if action *is* taken.

Based on: Discount factor d – .05
Capital cost C – 0
Scrap value – 50

Description		Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Total for Variable
Capital costs	C_p	0					1646	1646
Energy cost	E	1250	1250	1250	1250	1250		
	E_p	1250	1190	1134	1080	1028	979	6661
Maintenance cost	M	150	150	150	150	150	150	
	M_p	150	143	136	130	123	118	800
Repair/replacement cost	R	100	0	100	0	100	0	
	R_p	100	0	91	0	82	0	273
Scrap value	(S_p)	0					–32	–32
Total for Year (Present value)		1500	1333	1361	1210	1233	2711	9348
Running Total		1500	2833	4194	5404	6637	9348	

Table 7: Spreadsheet example of calculation of life cycle cost if action *is not* taken.

Forecasting/planning workload

The implementation of a preventive maintenance programme gives an immediately increased capability to forecast and plan the maintenance workload since the range of tasks and effort required are identified. The intention should be to spread these activities out in such a manner as to provide an even workload for maintenance staff.

It is accepted that a certain percentage of work still needs to be reactive and assuming that the target ratio of preventive to emergency maintenance can be achieved, it is possible to build in forecasts of the required reactive load.

J.1 SEASONAL EFFECTS

It is to be anticipated that the bulk of reactive maintenance work will be required during the winter months when systems are fully operational. Therefore, the planned effort on preventive maintenance during the winter should be reduced to accommodate the anticipated increase in reactive maintenance.

J.2 SLIPPAGE

Even in a well planned maintenance programme, some slippage of preventive work must be expected from time to time when there is an abnormal amount of reactive work required. This should not be a major concern and extra resources should not be secured to maintain the preventive plan. This only increases total costs.

Since the overall target ratio is assumed to be achieved, an abnormally high reactive load can be expected to be balanced at some time by an abnormally low reactive load. It is during these low periods that any slippage in preventive work should be made up.

J.3 PLANNING MULTIPLE CONTRACTORS

It is probable that local authorities will wish to reduce their financial risk by placing work with more than one contractor and that the volume of work for an authority should be sufficient to allow this.

Preventive and reactive tasks should be grouped so that a particular contractor works on a series of sites in a local geographic area, minimising non productive travelling time and maximising productive maintenance time.

Appendix K

The application of new technology to maintenance

A variety of new technologies are now becoming available which have the potential to assist both maintenance management and operations in schools. Some of the more important of these are presented.

K.1 BUILDING ENERGY MANAGEMENT SYSTEMS (BEMS)

These systems have two functions one of which is monitoring of environmental conditions and the other is control of the building services. Some systems are used only for monitoring whilst others provide both functions. Monitoring can include temperatures and fuel consumption and can aid energy conservation. Other variables which can be monitored are light levels, electricity demand, humidity and occupancy. The system can be programmed to provide alarms to warn the building manager when variables are outside a defined range. Monitoring and control can be carried out from a remote site by the use of a modem connection and can be of assistance to the maintenance organisation.

K.2 CONDITION MONITORING

Preventive maintenance is carried out at set intervals whether it is required or not. A more effective method may be seen as carrying out maintenance only when it is required. This means showing what factors constitute a requirement and having the ability to monitor when they occur.

A range of factors may be used to determine when the condition of a component is such that maintenance will be required. These may include lubricant temperature, vibration, pressure drop and so on. Condition monitoring may be carried out by a maintenance practitioner who takes readings of the monitored variable using an appropriate instrument. The readings are recorded and compared with those taken previously to produce a trend graph. This indicates when maintenance is likely to be required by establishing when the trend indicates that the maintenance value has been reached.

An alternative is to locate sensors at relevant locations and have these report to a BEMS. This can be programmed to accept the information, prepare and analyse trends and report on them. It should be remembered however that the sensors required for condition monitoring are likely to be additional to those required for energy management.

K.3 EXPERT SYSTEMS

Expert systems are a particular type of computer programme in which the knowledge of a human expert on a given subject has been embodied into software. The user can then consult the expert system, asking it the questions an expert would be asked and obtaining advice in the same way as an expert would give advice. For a well built expert system, the level of performance should be equal to that of the human expert.

Unlike other types of computer programme, expert systems can often work with incomplete data, they can explain why they want a particular response from a user and they can justify the advice given.

Expert systems can be used for many purposes but they have a particular value in maintenance where their diagnostic capabilities can be effectively utilised. Thus, given a particular fault, they may be able to identify likely causes from the symptoms given and recommend the remedial action to be taken.

Typical condition appraisal form

Component	Ref	Installed	Previous appraisal	Current appraisal	Action	Suggested cost of putting right
SPACE HEATING						
Boilers Fuel type: Oil Gas LPG Solid fuel Other						
Burners Burner type: Pressure jet oil Pressure jet gas Atmospheric gas Automatic stoker Other						
In-line pumps Centrifugal pumps Air handling plant						
Fan convectors Natural convectors Column radiators Panel radiators Pipework: Above ground Below ground Insulation: Boiler house Above ground Below ground						
Isolating valves Radiator/convector valves						
Tanks: Oil Water						
Meters: Oil Water Gas Heat						

DOMESTIC HOT AND COLD WATER SYSTEMS						
Central hot water Electric point heaters Gas point heaters Mains cold water Tank cold water						
Boilers Fuel type: Oil Gas LPG Solid fuel Other						
Burners Burner type: Pressure jet oil Pressure jet gas Atmospheric gas Automatic stoker Other						
Calorifiers Unvented cylinders						
In-line pumps Centrifugal pumps						
Pipework: Above ground Below ground Insulation: Boilerhouse Above ground Below ground						
Isolating valves Stopcocks Taps						
Tanks: Oil Water Meters: Oil Water Gas						

Appendix

CONTROLS						
Systems						
Control systems						
Components						
Central Station Control panel						
Optimisers Time switches/Programmers Wiring: Exposed Concealed Outstations Sensors Thermostats Controllers Valves Motors Actuators						

VENTILATION						
Systems						
Supply air Extract air Toilet extract Fume extract						
Components						
Supply fan Extract fan Duct work Fume cupboard Controls						

General comments by surveyor

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- simple fault tracing charts
- schedule of routine maintenance
- system of condition appraisal
- life cycle costs analyses

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