TECHNICAL MEMORANDA

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THE SELECTION AND APPLICATION OF HEAT PUMPS

1985

CIBSE

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FOREWORD

Heat pumps have been available as an item of engineering equipment since the late 19th century and so can scarcely be described as new technology. For most of this time, however, they have been applied as refrigeration machines generating cooling only, and rejecting as waste the heat produced in the process.

Recent years have seen a growth in the use of the heating only output of heat pumps and of combined heating and cooling applications, and it is this which has prompted the preparation of the Technical Memorandum.

As with all new applications of technology, some reactions to the use of heat pumps appear to be based on prejudice rather than knowledge or experience. The aims of this Technical Memorandum, therefore, are to provide some understanding of the concepts involved and, as the title indicates, to describe current practices in selection and application. It shows that heat pump design is based on proved experience and that units can be manufactured to a high standard of reliability. It is also seeks to show that a heat pump installation which is carefully designed and properly installed, commissioned and maintained will work effectively and efficiently.

This is the first CIBSE publication to deal specifically with heat pumps. It is hoped that a companion document giving more detailed design guidance will be produced in the future.

R. J. OUGHTON
Chairman
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M.J. Hicks
M. McCall
T. McDonnell
D.J. Martin
I. Wilkinson

Technical Secretary
K.J. Butcher

Co-ordinating Editor
S.P. Hodgson

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THE SELECTION AND APPLICATION OF HEAT PUMPS

1. GENERAL DESCRIPTION

Technically, all refrigerators are heat pumps as they transfer heat from a low temperature source to be released at a higher temperature. However, the designation "heat pump" is normally given to an equipment unit using either the vapour compression or absorption refrigeration cycles, where there is an intentional use of the rejected heat. Such units can provide heating or cooling, heating only or dehumidification. With the addition of a special reversing valve heating and cooling can be provided; such a unit is known as a reverse cycle unit.

Because most heat pumps are based on standard refrigeration practice the maximum output temperature from the condenser is about 55° C. This is sufficient for many applications as this maximum temperature is compatible with conventional heat emitter equipment. Specially designed single stage heat pumps or multistage machines used for particular industrial processes can provide higher temperatures at the condenser but where this also involves a high temperature lift, a performance penalty follows.

Industrial processes, hot water for domestic services and "wet" radiator or convector central heating systems are conventionally designed using higher temperatures. For these applications correct matching of both the heat pump and the heat emitter capacities to the design load is essential to ensure correct and efficient operation of the system. This is particularly important for the retrofitting of heat pumps into systems originally designed for high distribution temperatures.

Although a heat pump can be selected to deal with the whole of a heating load it may be advantageous to use it as part of a bivalent system. In this arrangement the heat pump satisfies the main heating requirement, and another heat source is used as a supplement or an alternative.

Where by design the heat pump is switched off at a predetermined temperature and a secondary source takes over to supply the full requirements then the system is called bivalent alternative.

Where by design the heat pump output is supplemented below a predetermined temperature by a secondary source to supply the full requirements, then the system is called bivalent supplementary or parallel.

Heat pumps are available in many types and sizes for various cooling, heating and dehumidification applications.

Because they take advantage of ambient or waste heat sources heat pump systems can operate with greater energy efficiency than conventional heating systems.

For air conditioning applications heat pumps operate over a wider temperature range and generally a longer period than conventional plant. The compressor also operates at much higher pressures and therefore requires to be more robust. However, for modern, well designed heat pumps these factors are taken into account so that design lives are equivalent to those of conventional equipment.

2. TYPES OF HEAT PUMP

Heat pumps may be classified in three ways, by

(i) Thermodynamic cycle
(ii) Source and distribution medium
(iii) Arrangement of components

Thermodynamic Cycle

The two principle thermodynamic cycles used for heat pump equipment are the vapour compression cycle and the absorption cycle.

In the vapour compression cycle, shown in Fig. 1, the temperature and pressure of the refrigerant vapour drawn out of the evaporator are increased by a mechanical compressor. Hot refrigerant vapour at high pressure is then passed to a condenser where the heat is rejected and refrigerant condensed to a liquid. The liquid refrigerant passes through an expansion device before finally returning to the evaporator at a lower pressure. Operation of the cycle requires the input of mechanical work from a motor or engine to drive the compressor.

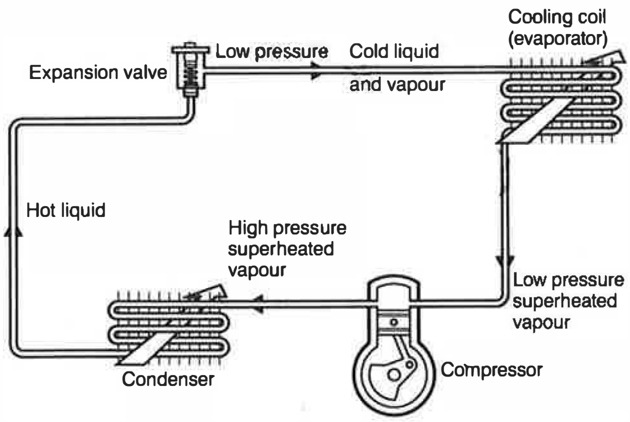

Fig. 1. **Vapour compression cycle.** ***(Reproduced by permission of the Electricity Council)***

Refrigerant temperatures and pressures for a typical cycle are given in Section B14 of the *Guide*[1].

Additional components are required where the cycle is to be reversed so that the heat pump can be used for heating or cooling. The main components are a reversing valve to reverse the flow of refrigerant to the two heat exchangers and an additional expansion valve and check valves.

The vapour compression reversing cycle for both the heating and cooling modes are shown in Figs. 2 and 3.

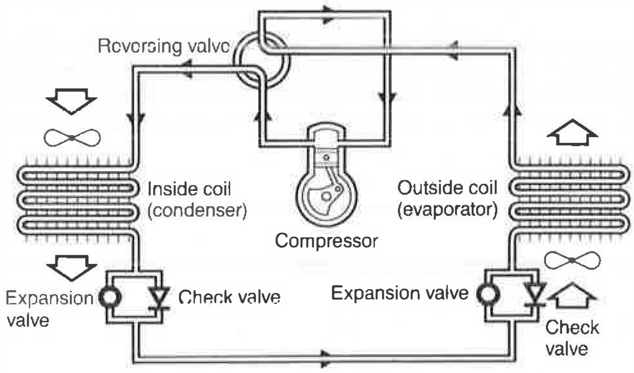

Fig. 2. Vapour compression cycle: heating mode. *(Reproduced by permission of the Electricity Council)*

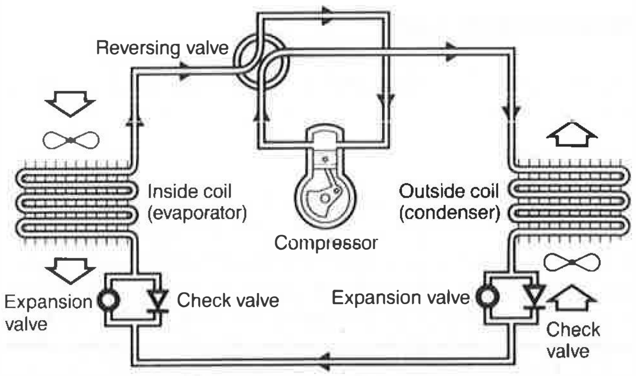

Fig. 3. Vapour compression cycle: cooling mode. *(Reproduced by permission of the Electricity Council)*

In the absorption cycle shown in Fig. 4, the evaporator, condenser and refrigerant fluid operate in a similar way to the vapour compression cycle. In addition, there is a secondary circuit around which an absorbent liquid is passed. The evaporated refrigerant vapour is absorbed into this absorbent liquid at low pressure, giving out heat as it does so. The solution is then raised to a high pressure by a liquid pump. High pressure refrigerant vapour is produced by the input of heat to the solution in a generator and this vapour passes to the condenser and finally to the evaporator through an expansion valve. The absorbent liquid, now partially depleted of refrigerant, passess back to the absorber through a second expansion valve. Operation of the cycle requires the input of heat energy from, for example a gas or oil burner or from a heat source such as steam, in order to produce refrigerant vapour from the solution in the generator.

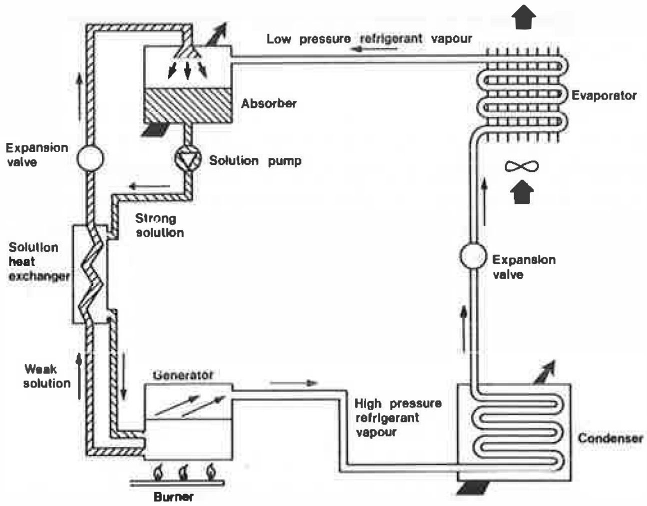

Fig. 4. Absorption cycle.

Table 1 lists some of the characteristics of the two cycles.

Table 1. Characteristics of heat pump cycles

Characteristic	Vapour compression	Absorption
Drive	Mechanically driven	Heat driven
Delivery temperatures	Generally up to 55°C, but can be up to 100°C and further developments may take this to 150°C	Up to 60°C
Heat addition	Heat recovery from on-site prime mover when used	Heat recovery from flue gases
Environmental	Compressor and motor may lead to noise problems. Noise from outside fans could also give problems	Potentially no noise problems
	Exhaust gases from on-site prime mover may need attention	Flue gas from burner may need attention
Working fluids	Fluorocarbon refrigerants available for most applications	Ammonia/water and water/lithium bromide, with new fluids such as fluorocarbons under development

Source and Distribution

Heat pumps can be classified according to type of heat source and heat distribution medium used, and are commonly referred to as such, e.g. air to water, air to air etc. Table 2 lists examples of heat source and distribution systems.

Table 2. Examples of heat source and distribution systems.

Heat source
Air – ambient
– heat recovery
Water – surface
– ground
– industrial waste
– cooling process
Soil

Heat distribution medium	Distribution system
	Air diffusers
Air	Individual units
	Radiators
Water	Underfloor coils
	Fan coils
	Induction units

Under certain circumstances the heat from a source is transferred to the heat pump by a secondary medium and an intermediate circuit. The secondary medium is normally used to avoid the problems of freezing and can either be brine or glycol, or a similar low temperature medium, e.g. fluorocarbon refrigerant.

Component Arrangement

A further classification is by the arrangement of components.

The examples shown below are for air to air heat pumps. The designations of self contained or split system are equally valid where the source and/or distribution medium is water.

Self contained units have all the components, with the exception of controls, in one casing or enclosure.

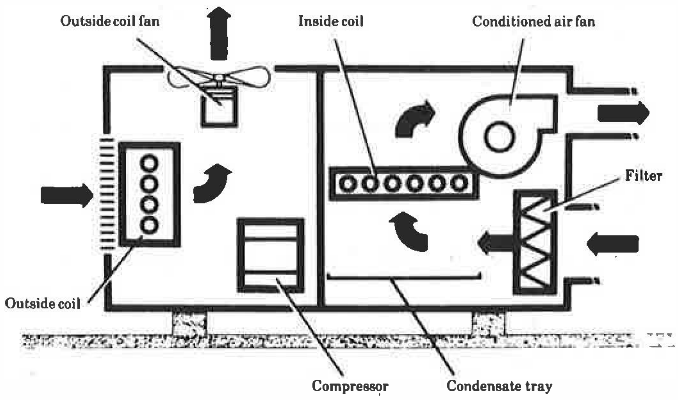

Fig. 5 Self contained unit. *(Reproduced by permission of the Electricity Council).*

Free standing units have a remote outdoor coil and fan separated from the other components.

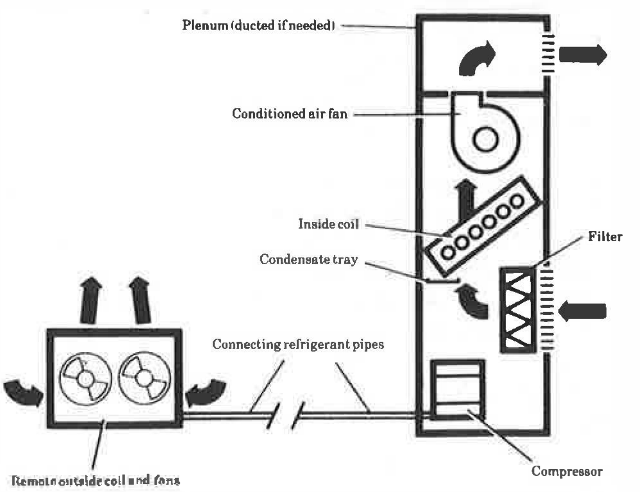

Fig. 6. Free standing unit. *(Reproduced by permission of the Electricity Council)*

Split systems have components in two casings or enclosures. One containing the indoor coil, fan and filter: the other containing the compressor, outdoor fan and coil.

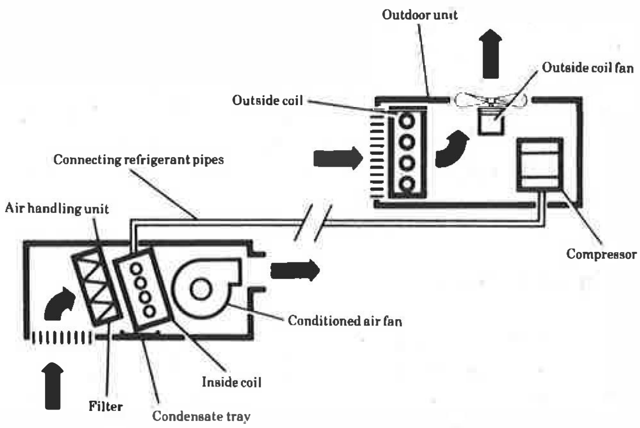

Fig. 7. Split system. *(Reproduced by permission of the Electricity Council)*

In both the free standing unit with remote outdoor coil and split system, the separated parts are joined with refrigeration pipework. These arrangements often use air as both source and distribution media. The development of equipment for refrigeration, air conditioning and chiller units has been mostly based on the vapour compression cycle, and the majority of heat pump products at present on the market also utilise this operating cycle. Consequently the design of compressors, motive power units and refrigerants have evolved much more quickly for the vapour compression cycle than for the absorption cycle. However, developments over the next few years may see absorption heat pumps coming into the market in greater numbers.

3. APPLICATIONS

The heat pump principles outlined in Part 1 can be exploited to provide useful heating, cooling or dehumidification dependent upon the choice of heat pump type and its configuration. The list below summarises the majority of current applications.

Heating Only

(i) Space heating; mainly central heating using radiators, convectors, and underfloor coils.
(ii) Water heating for hot water services, outdoor swimming pools etc.
(iii) Soil heating in glass houses, and similar horticultural uses.

These applications normally use air to water heat pumps.

Heating and Cooling

(i) Environmental control for shops, supermarkets, department stores, offices and public buildings.
(ii) Specialist service functions in clean rooms, computer rooms, beer cellars etc.
(iii) Process control of mushroom houses, seed potato stores and similar agricultural uses.

Reversible air to air heat pumps are most frequently used to provide space heating or cooling as required, especially for single zone applications. For multi-zone applications reversible air to water heat pumps are usually used. Non-reversible air to water heat pumps are being used to simultaneously provide cellar cooling and hot water (which can be stored) for washing purposes in licensed premises.

Dehumidification

(i) Humidity control for stock protection in warehouses, munitions and archival storage etc.
(ii) Condensation control in housing, swimming pools etc.
(iii) Process drying such as timber, malt, pottery, clay etc.

Where dehumidification is the principal requirement, air to air heat pumps using a single air stream are used. The use of a heat pump dehumidifier is often more effective and energy efficient than conventional methods of humidity control.

Heat Reclaim

(i) Extract or exhaust air from shops, offices, hospitals and any process or system where recirculation is inappropriate.
(ii) Humid air such as from swimming pool halls.
(iii) Waste water from showers, commercial dishwashers etc.
(iv) Heat rejected from chiller plant.
(v) Cooling water or waste products from processes such as injection moulding.

Heat pumps are used for heat reclaim where the source temperature is too low for direct use but higher than available ambient sources. The heat pump can upgrade the temperature of the source so that it can be efficiently re-used for heating. The type of heat pump used will depend on the heat reclaim medium and on the requirements of heat distribution. Where an engine driven heat pump is used waste heat can also be recovered from the exhaust and engine coolant to increase the output temperatures (see also Part 8).

4. PERFORMANCE EVALUATION

The performance efficiency of heat pumps, like any refrigeration system is expressed as coefficient of performance. All coefficients of performance relate to the ratio of energy or heat output to the energy input.

The heat pump industry has, over a number of years, also used the term coefficient of performance to indicate a performance efficiency ratio. Because of this, there are now theoretical uses of the term COP related directly to the refrigeration cycle and practical uses indicating efficiency.

Theoretical COP

For the vapour compression cycle where a cooling output is considered, the COP is the ratio of refrigeration effect to the work done by the compressor. This is known as the COP_R and is normally quoted in the refrigeration unit compressor data. A similar COP based on the heating output is the ratio of heat from the condenser to the work done and is known as COP_H.

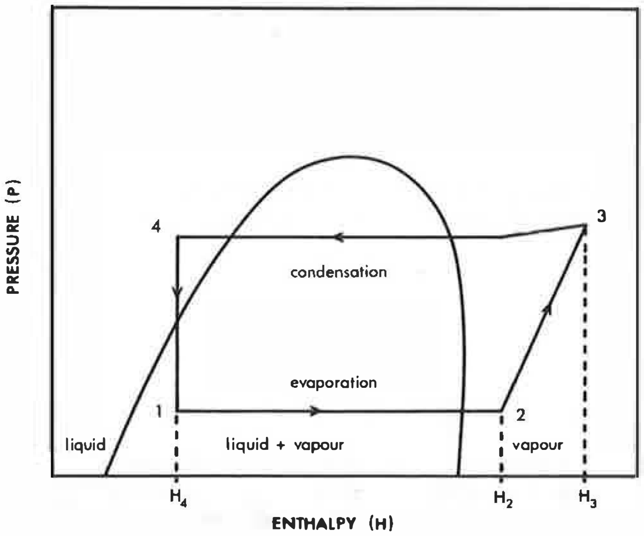

Fig. 8. Pressure enthalpy diagram for the vapour compression cycle.

From Fig. 8, the theoretical coefficient of performance is given by:

$$COP_H = \frac{H_3 - H_4}{H_3 - H_2}$$

i.e.:

$$COP_H = \frac{\text{enthalpy change due to condensation of vapour}}{\text{enthalpy change due to compression of vapour}}$$

For the absorption cycle, the most useful measure of COP is the ratio of heat output from the condenser and the absorber to the heat input to the generator, i.e.

$$\mathrm{COP}_H = \frac{Q_C + Q_A}{Q_G}$$

Practical COP

The coefficient of performance for the heat pump itself is termed the appliance COP, and this parameter is useful when comparing one heat pump with another. It would normally be measured by the manufacturer in his test laboratory with set inside and outside conditions. There are no British Standards or agreed International Standards on methods of testing, conditions of test or measurements to be taken. It has become accepted industry practice when considering heat pumps for heating, however, for the input energy to include energy used by the following in addition to the energy used by the compressor:

(i) Any outdoor fans or pumps required by the low temperature source.
(ii) The internal controls such as motorised valves and solenoid valves.
(iii) Crankcase heater.
(iv) Any supplementary energy used during a defrost cycle.

As the energy used for the distribution fans or pumps to the system are traditionally omitted from boiler or warm air heater efficiency rating, it is considered that the same practice should be followed for heat pumps. For engine driven heat pumps the appliance COP should include the useful heat actually recovered from the engine exhaust etc. as part of the output. Legislation, standards or local practice may redefine this in the future.

The appliance COP should not be used to determine the running costs of an installation but as one of the criteria for selecting a particular heat pump.

Overall system efficiency can be established and expressed as a COP by including the energy input to supplementary heating and distribution fans or pumps as part of the total energy input. It is not a true COP because items which are not part of the heat pump operation are also considered. It does, however, give an indication of the total energy used by the system compared to the heat output and thus enable an estimation of consumption and running costs to be established. Where the energy or fuel used throughout the system is the same, (normally only the case with electricity), then to establish the system COP the value of the heat not provided through the condenser can be considered as having a COP of 1. However, where more than one fuel or energy source is used such as in engine driven, absorption or electric/fossil fuel bivalent systems, then the individual costs of each form of energy used in the system must be evaluated to provide a satisfactory estimation of running costs.

The use of seasonal efficiency for conventional heat generators and systems is described in Section B18 of the *Guide*[2]. This enables a comparison to be made with other forms of heat generators on a seasonal basis.

The seasonal coefficient of performance of a heat pump is defined as the appliance COP averaged over the heating season.

The value of coefficients of performance are dependent on compression ratios, temperatures, cycle arrangements, source and distribution temperatures and will also vary depending on which of the coefficients of performance is being considered.

Table 3. Typical coefficients of performance.

Theoretical COP			Actual COP		
Rankine	COP_R	COP_H	Appliance	System	Seasonal
7.22	4	5	3.0	2.3	2-2.5

Table 3 shows the variation of COP values for a typical vapour compression air to air heat pump using ambient air as a source. The variation illustrates the need to understand which COP is being quoted or compared and at which conditions. In any case, COP is only one indication of the viability of a particular heat pump option, and a full economic assessment is always necessary in equipment selection.

5. SELECTION PROCEDURE.

The detailed selection of a heat pump will depend upon several variables to do with its application and pattern of operation. Having calculated the heating, cooling and dehumidification loads using normal calculation procedures, selection will be based on the following:

Source and distribution
Site considerations
Equipment sizing
Economics

Source and Distribution

The decision on source will normally depend on availability and convenience: source temperature being important for its effect on the efficiency and control of the heat pump. Consideration should also be given to the possibilities of heat reclaim.

The specification of the heating or air conditioning system to be used is the most important factor in relation to heat pump distribution selection. Distribution temperature is an important consideration as this affects efficiency. The decision on source and distribution media will determine the type of heat pump eg air to air etc.

Because of the variation in temperature of some heat sources the refrigeration system design pressures for heat pumps are far more critical than for conventional cooling units. Hence, it is very important to ensure that the heat pump selected is capable of operating within the ranges expected of it. It is also essential to ensure that the heat output from a heat pump can be dissipated into the distribution system. Careful selection of the distribution fans or pumps is vital therefore, and consideration should be given to using buffer tanks with water systems.

Site Considerations

The location of the unit should be considered in relation to heat source and distribution positions, and other factors such as noise, aesthetics, fuel availability and access for service and maintenance.

When selecting equipment the designer should have due regard for the provisions of the Control of Pollution Act 1974 Part III: Noise[3], and any aspects of common law relating to the possible nuisance arising from the noise level. Excessive noise may be produced at the outside fan or coil, at the compressor, or in the case of fossil fuel driven heat pumps, at the engine.

What might be acceptable to the occupants of a building benefiting from a heat pump may not be to neighbours annoyed by the noise of the outside unit. Noise from a unit may be masked by background noise (e.g. traffic) during the day, but be very intrusive and therefore unacceptable at night.

The unit selected should be designed so as to minimise the generation and transmission of noise by the correct selection of components such as fans, and the use of anti-vibration mounts or connections. Lining of unit casings with suitable sound absorbing material can minimise resonance, but acoustic attenuators and/or noise barriers may be necessary to provide further sound control. Further information may be found in Section B12 of the *Guide*[4].

Equipment Sizing

Firstly, the most important load requirement; cooling, heating, or dehumidification should be determined.

If cooling is the major requirement the heat pump should be selected to deal with this, and the heating output checked against the heating load required. Usually, but not always a heat pump selected for the cooling load will have more than enough capacity to deal with the heating load. Where the heat output is less than required for the heating design condition, either the size of the heat pump must be increased, or a balance point temperature must be determined and a bivalent system selected to operate at the lower temperatures. A simple graph of heat losses or output against external temperature will indicate the balance point with a particular heat pump. Fig. 9 shows a typical example of a bivalent system where the balance point is 3°C, for a design winter temperature of −1°C.

If heating is the only or major requirement then four important considerations need to be taken into account.

Firstly a careful analysis must be made to determine whether the heat pump should be selected to meet the whole requirement at system design temperature, or whether a bivalent supplementary or alternative system would be more suitable.

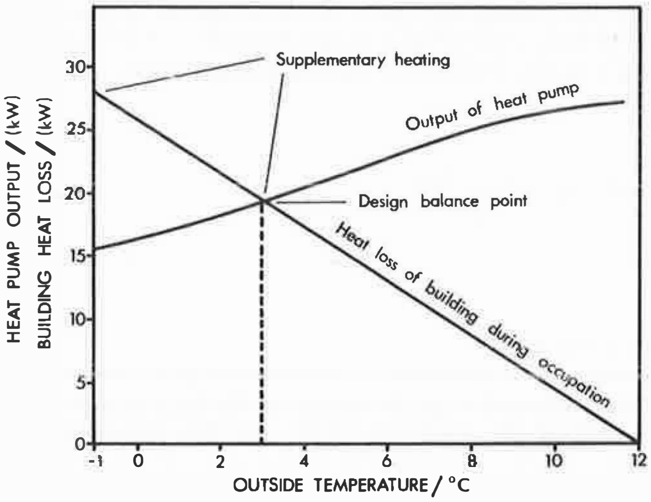

Fig. 9. Balance point temperature.

Secondly as the heat pump performance changes with source and distribution temperature variations, its performance at system design conditions as well as the balance point must be determined. Having decided the appropriate balance point it is still necessary to plot equipment performance over a wider temperature range to ensure that the unit selected is suitable.

For air source heat pumps consideration must be given to the periodic defrosting of the outdoor coil, as this can effectively derate its capacity at low external temperatures. See also Part 7.

Lastly, if intermittent heating is required there may be a need for additional capacity to allow for preheat.

It is important to make sure the right balance is achieved between the size of the heat pump and the supplementary or alternative heating to make full use of the heat pump performance characteristics. If the heat pump is too small it will fail to meet expectations, if oversized it will operate less efficiently over its whole range. Appendix 1: The Heating Analysis Chart describes a method for assessing balance point choice and energy requirements thoughout the heating season.

The heat pump dehumidifier removes moisture by cooling the air to below dew point and then reheating that air using the heat rejected through the condenser. The dehumidification load is usually calculated in terms of latent heat and the heat pump should be selected using this data. If however the manufacturer's selection data is a moisture removal rate then the latent heat loads will need to be changed into appropriate units using psychrometric charts or tables (see Section C1 of the *Guide*[5].). Heat pumps used for the dehumidification of swimming pool halls are outside the scope of this Technical Memorandum.

Where a heat pump is used for heat reclaim its size will be determined by the amount and temperature of heat available for recovery. The heat to be reclaimed becomes the source and the selection procedures will be similar to those for heating only applications. It is of particular importance to ensure that the heat for reclaiming is available during expected peak demand times. Caution should be applied when selecting a standard commercial heat pump that the heat source temperature does not exceed the design limits of the unit.

Economics

Economic considerations are particularly important in the selection of heat pumps. A full economic analysis of the proposed selection will help to determine the optimum size of the unit, which energy sources are appropriate and which tariffs would be favourable. It will also help determine the suitability of a bivalent system and the outside temperature at which the alternative or supplementary system should come into operation. Appendix 2: Economic Appraisal describes a method for economic appraisal of the heat pump investment. Appendix 1: The Heating Analysis Chart is also useful for assessing proportions of energy contributed by the various components of the system.

Standby Heating

The same considerations should be given to heat pump systems for standby as are given to other systems.

6. CONTROL REQUIREMENTS.

Correct control of the heat pump system is vital to maintain performance. The general requirements for system controls to utilise and regulate distribution of heat are covered by the CIBSE Applications Manual, *Automatic Controls*[6]. Particular care must be taken with the heat pump system to avoid rapid cycling as this is both harmful to the equipment and inefficient in energy usage.

Controls can be divided into two groups: those installed for unit protection, and those for the correct operation of the unit and system.

Controls for Unit Protection

Vapour Compression Equipment

The controls required for unit protection, which may be integral to the vapour compression heat pump, are as follows:

- *(i)* A high pressure cut out of the manually reset type situated immediately after the compressor(s). In addition, there should be some means of safely relieving pressure from the compressor and refrigeration circuit. (For further guidance see the manufacturer's instructions and BS 4434[7]).
- *(ii)* A low pressure cut out situated between the evaporator coil(s) and the compressor. Manufacturer's data should provide guidance on resetting. An oil pressure cut out should also be fitted to isolate the compressor if the lubricating oil pressure falls below a predetermined level.
- *(iii)* A compressor crank case heater to prevent damage due to oil dilution.
- *(iv)* A compressor delay start to ensure that the compressor will not operate until the refrigerant pressures have had time to equalise throughout the system.
- *(v)* A flow switch, or pressure differential device in cases where failure of air or water flow would result in damage to the appliance or equipment.

Absorption Equipment

Controls required for protection and safety of the absorption heat pump form an integral part of the unit and are as follows:

- *(i)* High temperature cut-out in the generator, usually provided with manual re-set.
- *(ii)* Refrigerant pressure relief valve located between the generator and the condenser, with the outlet piped to an outside location to permit safe blow-off of refrigerant.
- *(iii)* Flame failure device on the fossil fuel burner.
- *(iv)* Differential thermostat on the hot water supply line (if water is the heat distribution medium).
- *(v)* Air flow switch in the evaporator which senses the correct flow-rate across it.

All these elements should be interlocked with the solenoid valve situated in the fuel supply line in order to activate an emergency burner shutdown. In addition, if a hazardous refrigerant is employed (e.g. ammonia) a gas leak detector should be fitted for indoor installations, which should provide visual and acoustic alarm and should be wired into the main protection circuit.

Controls for Unit and System Operation

For vapour compression cycle heat pumps with more than one compressor, automatic controls must be arranged to provide a time delay between each compressor starting. For an air sourced heat pump a means of defrost is required if it is to be used with outside temperatures below 6°C. The unit should incorporate adequate control to allow a complete defrost of the evaporator coil, whilst ensuring that the defrost sequence is neither initiated nor continued unless essential. (See also Part 7).

The operational controls of an absorption heat pump should be similar to those for a vapour compression heat pump. They should include an ignition time delay switch to prevent excessive cycling and defrost control arrangements or, in their absence, an ambient temperature sensor to activate the switch-over to supplementary heating in a bivalent mode.

Controls for Bivalent Operation

When operating in a bivalent supplementary mode a system will require, as a minimum, two stage automatic controls to control the use of the heat pump at source temperatures above the balance point. Consideration should also be given to the use of fully sequenced controls. An outdoor thermostat should be used with external source heat pumps to ensure that any supplementary heating will not operate above the balance point. For pre-heat periods under cold conditions, consideration should also be given to the use of an optimiser to maximise the use of the heat pump by increasing the pre-heat time.

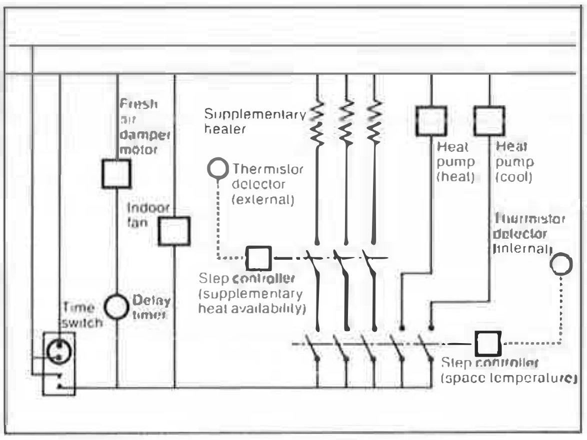

Fig. 10. Example controls: bivalent supplementary mode.

Figure 10 shows an example control diagram for a single stage heat pump with bivalent supplementary electric heaters. The diagram shows multi-staging of the supplementary heater battery, together with damper controls and a time switch set to close the outside air dampers when the space is unoccupied. This ensures that the outside air load, which is not required during unoccupied periods, is not imposed on the heat dump during pre-heating.

When used as a heat recovery device, the heat pump must be controlled to match the heating demand which can be used efficiently, rather than the total recoverable heat.

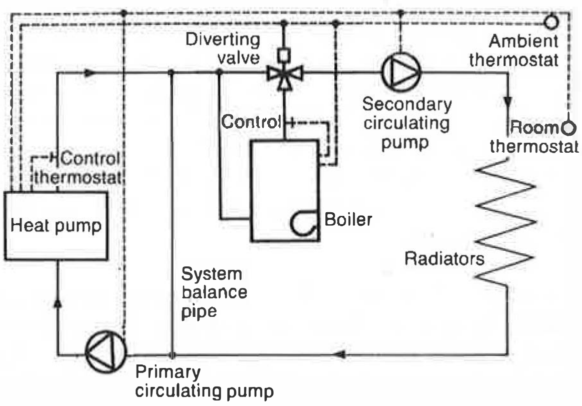

Fig. 11. Example controls: bivalent alternative mode.

Figure 11 shows an example control diagram for an air to water heat pump operating in the bivalent alternative mode with an oil-fired boiler, serving a conventional radiator system. Operating the system in this mode avoids the possibility of higher temperature return water being circulated through the heat pump and enables a higher flow water temperature to be delivered to the system during low outside temperature conditions.

Where electrically driven heat pumps are used they can have a considerable effect on the maximum demand characteristics of the building. Consideration should therefore be given to the integration of load management as well as environmental control to ensure the most effective use of tariffs.

Building energy management systems incorporate control features that are particularly compatible to heat pump installations, for example the ability to anticipate on a daily basis variations in outdoor air temperature. This can be particularly important for air source heat pumps as the decrease in coefficient of performance due to lower external temperatures coincides with increased building heat losses.

An energy management system can be programmed to advance the heat pump starting time to compensate for diurnal fluctuations, and they can be more readily programmed for a range of start-up or opening times than a conventional controller. The use of optimum start devices for pre-heating and off-peak electricity tariff use should also be considered to help reduce maximum demand.

7. DEFROST AND ITS EFFECTS.

Where moist outside air is used as a source of heat, ice will form on the outdoor coil heat exchanger surfaces when the coil evaporating temperature falls below 0° C. Frosting can occur at air temperatures below 6° C, and the rate of formation of ice will depend on the relative humidity and temperature of the ambient air. Excessive frosting will reduce the heat transfer to the refrigerant and create a resistance to air flow, thereby reducing the unit's performance. If this ice is not removed it will continue to build up until the coil becomes completely blocked and safety controls on the refrigeration circuit stop the unit operating.

There are three usual methods of defrosting the outside coil:

(i) Reversing the refrigeration cycle so that the outside coil becomes the condenser.

(ii) Hot gas by-pass, where a proportion of hot gas is allowed to by-pass the circuit and is taken directly from the compressor to the outside coil.

(iii) Direct acting electric resistance heaters attached to the outside coil to operate only for defrost.

Operation of defrost can be initiated by time control, temperature sensors or pressure sensors. Time control operates the defrost for a short period, dependent on the refrigerant temperature, every one or two hours of unit operation. Temperature sensors measure the change in refrigerant temperature caused by the ice formation and operate the defrost. Pressure sensors work in a similar way by sensing the increase in air pressure drop across the coil caused by the formation of ice. The most common method of control is a combination of time and temperature sensors.

The energy used for defrost is small, amounting to between 2% and 8% of the total winter energy usage of the heat pump. As the unit is not providing any useful heat during defrost the overall performance and capacity will be reduced. Additional heating should be supplied if necessary to make up any shortfall.

8. HEAT PUMP DRIVES.

Vapour Compression

The main component of the vapour compression refrigeration cycle is the compressor, and this needs to be driven by a suitable power source. The drive can be by electric motor, gas or diesel internal combustion engine, steam turbine or similar external combustion engine.

The majority of heat pump compressors of all sizes considered in this Technical Memorandum are driven by electric motor. A hermetic compressor has the drive motor contained and permanently sealed within a refrigerant-tight housing, with no means of access for servicing internal parts in the field. The semi-hermetic compressor also has the drive within a refrigerant-tight housing but with removable covers for maintenance access. All other compressors have a separate motor (with shaft seals to ensure no refrigerant loss) and are known as open compressors. Hermetic and semi-hermetic compressors allow the heat from the motor to be available to the refrigerant; this can be advantageous in heating applications.

Inductive loads can have adverse effects on the electricity supply network if this is insufficient to meet the increased demand. It is essential that such effects do not inconvenience other users. The Supply Authority is required to ensure such a situation does not occur and will therefore restrict the load which can be connected without reinforcement, or will impose special starting current limitations. This applies particularly to single phase supply. There are also guidelines with respect to motor size which can be accepted on to the supply network without reference to the Supply Authority. Equipment incorporating electric motors will, in normal circumstances, be accepted up to the following input ratings:

1kW single phase 240v

3kW single phase 480v

4.5kW three phase 415v

Such acceptance is without qualification as to starting current or method of starting, providing that the relevant single or three phase supply is available at the premises. There is also a qualification with regard to the numbers of starts a unit may make in a stated period of time. Methods of "soft starting", that is to lessen the required starting current, may be used to reduce this problem. In larger units where three phase supply is required, appropriate starting arrangements and power factor correction need to be considered. Further information is available from the local Electricity Board.

An open compressor can also be driven by an internal combustion engine. Such an engine could use a number of fossil fuels but these are normally natural gas or diesel fuel. The advantage of an engine is its ability to match the output to load conditions by changing the engine speed or fuel supply rate.

Currently employed gas engines with shaft power greater than 100kW are of proven design and operate at low speeds. The majority of them are four stroke, normally aspirating (or turbocharged) Otto cycle engines of in-line or V-type design with up to 16 cylinders. Some engine manufacturers have succeeded in converting automotive petrol engines into compact gas driven heat pumps with shaft power of 25-50kW and heat output up to 100kW. The economics of their operation make gas engines particularly attractive in applications greater than 100kW. Reciprocating open compressors are coupled directly to the engine, whilst rotary compressors normally require a gear unit.

For information on safety and use of gas engines for heat pumps reference should be made to the British Gas Code of Practice IM/17[8].

Diesel engines generally have a higher conversion efficiency than Otto engines but their use is mainly restricted to large scale applications.

Where a heat pump is used for heating or dehumidification, use can be made of the heat recovered from the engine exhaust and water cooling jacket to increase the overall efficiency and boost the outlet water temperature. When used for cooling, however, this recovered heat must be rejected. This type of unit is therefore most useful for large scale applications where heating or dehumidification is required for a major proportion of the year.

Care should be taken to ensure the compatibility of the engine and compressor and it is preferable to obtain a matched set from the manufacturer. Suitable arrangements need to be made for the provision of combustion air, the removal of exhaust gases and the attenuation of noise output.

The controls for the engine and refrigeration cycle must be interactive so that the engine load can match that of the heat pump, and should be as recommended by the manufacturer.

Large steam turbines can be used to drive open compressors but these, together with any wind or water drives, are outside the scope of this *Memorandum*.

Absorption Cycle

The absorption cycle requires high temperature heat for operation and there are no moving parts other than auxiliary pumps and fans requiring an electrical supply. With absorption units heat is delivered to the generator at temperatures between 120 and 180°C. The heat may be provided by steam or high temperature hot water, if available, or alternatively by purpose designed gas burners. These burners form an integral part of the unit and are mainly of the induced draught, pre-aerated design. Sensible and latent heat recovery from the flue gases is often added to enhance the overall efficiency.

9. COMMISSIONING AND MAINTENANCE.

Commissioning

To ensure reliability of both the operation and performance of the heat pump, correct commissioning after installation must be undertaken on site in accordance with the manufacturer's instructions. This commissioning should only be carried out by skilled and expert personnel.

Checks should be made at the following stages

(i) Pre start up.
(ii) Heat pump running.
(iii) System commissioning.

Pre start up.

Prior to starting up the heat pump, checks to be made should include the following:

(a) Electrical wiring has been checked and tested for continuity and earth leakage.
(b) Valves or dampers in the system are in the position required by the design.
(c) Any circulation pumps or fans are on.
(d) Refrigerant valves are open.
(e) The crank case heater is in operation for the time specified by the manufacturer.
(f) Any assisted start unit has been properly set up.
(g) Thermostat or temperature controls are in the desired mode, i.e. heating or cooling.
(h) The timing of compressor delay starts are correct.
(i) The setting of any controllers or thermostats within the heat pump are correct.
(j) The air or water flows to the two coils are not in any way restricted and no unwanted recirculation can occur.

Heat pump running

While the plant is in operation the following checks on the heat pump should be made:

(a) Settings of high and low pressure switches and the adjustment if necessary. These settings should be recorded.
(b) Suction and discharge refrigerant pressures are measured and recorded.
(c) The adjustment of the thermostatic expansion valve by means of superheat measurement. This setting should be recorded.
(d) Temperature differences across solenoid valves, reversing valves etc, where fitted.
(e) The direction of fan or pump rotation.
(f) The operation of defrost cycle in accordance with the manufacturer's instructions.
(g) Check for any refrigerant leakage, particularly from any flared connections.
(h) Carry out a performance check to establish the coefficient of performance relative to the ambient temperature.
(i) Check the running and starting currents of the compressor and of any indoor or outdoor fans and pumps.

System commissioning

While the plant is in operation the following checks on the system should be made:

(a) The outside thermostat or sensor is controlling in accordance with heating requirements.
(b) The space heating or water heating thermostat control and any cooling controls are in accordance with the specification.
(c) The supplementary heating will not operate unless the heat pump is called to operate and the outdoor temperature is less than the setting of the outdoor thermostat (except on manual override in the event of a heat pump failure).
(d) The operation of all control valves and/or dampers to ensure the correct conditions are achieved.

Before the system is handed over the customer should be fully instructed in its operation and be provided with printed copies of necessary operating and maintenance instructions and supporting literature.

The following is a list of equipment necessary to allow recommended commissioning to be undertaken:

(a) Pressure gauges for refrigerant circuit.
(b) Refrigerant gas leakage tester.
(c) Adequate means of measuring surface temperatures around the refrigerant circuit and across the condenser.
(d) Pressure gauges or differential pressure gauge for measuring the water or air pressure difference across the condenser.
(e) A clamp on ammeter to measure the current and voltage and therefore allowing the energy input to be estimated.
(f) Electrical tester for measuring continuity of circuits.
(g) Information from the manufacturer regarding the relationship between pressure drop and water flow or air flow rates through the condenser.
(h) Information from the manufacturer regarding the superheat settings for the calibration of the thermostatic expansion valve.
(i) Information from the manufacturer on the settings of each thermostat and pressure switch within the circuit.
(j) Sling psychometer for measuring ambient wet and dry bulb temperatures.
(k) A tachometer to permit checks of speeds of rotation.
(l) A vane anenometer and pitot tube for airflow measurements.

Maintenance

The regular maintenance of heat pump systems is recommended to sustain operating efficiency and extend the working life of the plant. Without properly planned maintenance, additional expense can be incurred through failures and increased energy consumption.

There should be at least one maintenance visit per year by a qualified service engineer but more may be necessary depending on the size and complexity of the installation. Each maintenance visit should cover at least the following:

- *(i)* A careful check of the general condition and actual operation of the plant and consideration of operators' comments.
- *(ii)* A check on the control settings in relation to design requirements and manufacturer's instructions.
- *(iii)* A check on all components, cleaning and adjusting as necessary with particular emphasis on the outside coil to ensure that it is free from debris.
- *(iv)* A check and adjustment of the charge of the refrigeration circuit as required by manufacturer's data
- *(v)* The inspection of safety and operation of the electrical or gas system.
- *(vi)* A performance check on the operating efficiency of the heat pump at ambient conditions.
- *(vii)* Advice to the user on any immediate or pending repairs or replacements.

In addition the operator should be encouraged to ensure that the outdoor unit is free from debris, that all filters are regularly cleaned and that gulleys, condensate pipes, trays etc, are kept clear.

REFERENCES

[1] CIBSE Guide, Section B14, Refrigeration and Heat Rejection, Chartered Institution of Building Services Engineers, London, 1972.
[2] CIBSE Guide, Section B18, Owning and Operating Costs, Chartered Institution of Building Services Engineers, London, 1972.
[3] The Control of Pollution Act 1974, Part III: Noise, HMSO, London 1974.
[4] CIBSE Guide, Section B12, Sound Control, Chartered Institution of Building Services Engineers, London, 1972
[5] CIBSE Guide, Section C1/2, Properties of Humid Air, Water and Steam, Chartered Institution of Building Services Engineers, London, 1975.
[6] CIBSE Applications Manual, Automatic Controls and their Implications for Systems Design, Chartered Institution of Building Services Engineers, London, 1985.
[7] BS 4434: Part 1: 1980 and Part 2: 1976, Requirements for Refrigeration Safety, British Standards Institution, London.
[8] British Gas Code of Practice for Natural Gas Fueled Spark Ignition and Dual-Fuel Engines, publication IM/17, British Gas, London, 1981.

APPENDIX 1

Heating Analysis Chart

The heating analysis chart* is a way of assessing the energy requirements of a system throughout a heating season. The load requirements of the heat pump and any supplementary heating can be depicted on this chart, a number of options plotted, and their effects on the overall energy consumption assessed. A simplified form of the chart is shown in Fig. A1 for a design condition of −4°C external temperature, an internal temperature of 20°C and a heating season of 273 days.

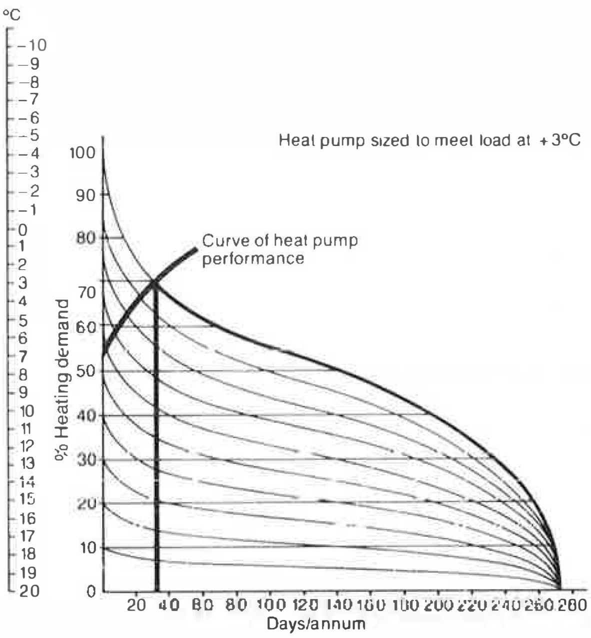

Fig. A1. Heating analysis chart. *(Reproduced by permission of the Electricity Council)*

The vertical scale showing the ambient temperature may also represent the percentage design day heating demand. The horizontal scale represents the days per year and has been shortened to the number of days for the recommended heating season. The area under the characteristic S-shaped curves represents the annual heating energy requirement assuming no fortuitous gains.

A series of S curves under the principal curve may be used to represent changes in total annual heating requirement for a reduction in design day heating demand or temperature. The analysis chart depicted is for London weather data but curves are available for other locations throughout the UK. From information supplied by the manufacturer the output curve of the heat pump against various ambient temperatures may be plotted as a percentage of the load at −4°C. The area below this curve represents the heating energy supplied by the heat pump. The area above the heat pump curve but below the S curve represents the energy supplied by the secondary source in bivalent supplementary operation. If a vertical line is dropped from the point where the heat pump curve crosses the S curve, known as the balance point, the area to the right of the line represents the energy supplied by the heat pump, the area to the left the energy supplied by the secondary source in bivalent alternative operation. Any fortuitous gains from lighting, people etc. can be represented by a horizontal line, where the gains are expressed as a percentage total demand. The calculations for energy consumption using the heating analysis chart for various locations are normally carried out using a computer.

*Available from the Electricity Council, 30 Millbank, London SW1 4RD

APPENDIX 2

Economic Appraisal

In many cases, a heat pump system will be one of a number of competing equipment types for a particular application. To ensure that the selection of equipment is based on comprehensive information, a proper economic appraisal should be made taking into account fuel operating costs, maintenance costs and capital expenditure for each type of equipment under consideration.

Such an appraisal could be based on a simple payback period comparison, and this method is valuable for an initial examination of the project. A more appropriate method of economic appraisal however is the net present value method using a discounted cash flow analysis. This takes into account benefits occurring over the estimated lifetime of the equipment and relates these to the first cost of the equipment.

In this method, a comparison can be made between heating equipment types which incur different expenditure patterns over time. Each expenditure pattern is discounted over the life-time of the equipment back to the present by using an appropriate rate of discount. The net present value (NPV) is the algebraic sum of the present values of all costs and savings during the life of the equipment, calculated using a standard discount rate. The discount rate is the real rate of return on invested capital; in essence this is the investment interest rate with the inflation rate subtracted from it. The discount rate applied to the public sector in the UK is laid down by the Treasury and at present stands at 5 per cent per annum.

The NPV is calculated using the formula:-

$$\mathrm{NPV} = -C_o + \frac{S}{r}\left(1 - (1+r)^{-N}\right)$$

where:

- C_o = initial additional cost of the heat pump purchase and installation in comparison with the alternative equipment
- S = savings per year due to reduced heat pump fuel costs less any additional annual maintenance costs for the heat pump.
- r = standard annual discount rate after allowing for general inflation.
- N = lifetime of the heat pump in years

The formula can be modified to take account of an annual rise in the real cost of fuel by using:-

$$\mathrm{NPV} = -C_o + S\left(\frac{1 - \left(\frac{1+r}{1+f}\right)^{-N}}{\left(\frac{1+r}{1+f}\right) - 1}\right)$$

where:

- f = rate of fuel cost rise in real terms (assumed constant over the lifetime of the heat pump).

In situations where the NPV calculation leads to a positive net present value the investment can be considered economically viable. In all other cases the investment would be considered uneconomic.

Further guidance can be obtained from Section B18 of the *Guide*[2].

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