GOOD PRACTICE GUIDE 271

Selecting and specifying new paint curing and stoving ovens

GOOD PRACTICE GUIDE 271

ENERGY EFFICIENCY

BEST PRACTICE PROGRAMME

SELECTING AND SPECIFYING NEW PAINT CURING AND STOVING OVENS

This Guide is No. 271 in the Good Practice Guide Series. The Guide will help you select, specify, install and maintain a paint curing or stoving oven that is energy efficient as well as meeting all your other needs.

It is estimated that energy used in paint curing and stoving costs the engineering industry more than £100 million per year. It is known within the industry that many ovens are not energy efficient. Ovens are often used without having in place the best operating and maintenance procedures to maximise energy efficiency.

To make matters worse, 60-85% of all the energy used is lost as waste heat, either in the exhaust flow or through the oven walls.

This Guide is aimed at engineers and managers in the engineering industry who are responsible for the selection, installation and operation of paint curing and stoving ovens.
It will help you to:

- identify the right type of oven for your purposes;
- discuss important issues for energy efficiency with your oven supplier when selecting your oven system;
- incorporate energy running costs into the financial analysis such that the cheapest oven over its lifetime is chosen;
- ensure that your oven is installed and commissioned properly;
- ensure that your oven is properly maintained.

This will ensure that your energy costs are kept to a minimum, making you more competitive.

Prepared for the Department of the Environment, Transport and the Regions by:

ETSU
Harwell
Didcot
Oxfordshire
OX11 0RA

and:

Entec UK Ltd
Windsor House
Gadbrook Business Centre
Gadbrook Road
Northwich
Cheshire
CW9 7TN

First published March 1999

LIST OF RELEVANT GOOD PRACTICE GUIDES

2. ENERGY SAVING WITH ELECTRIC MOTORS AND DRIVES (REVISED)
126. COMPRESSING AIR COSTS
200. A STRATEGIC APPROACH TO ENERGY AND ENVIRONMENTAL MANAGEMENT
213. SUCCESSFUL PROJECT MANAGEMENT FOR ENERGY EFFICIENCY
215. REDUCING ENERGY COSTS IN INDUSTRY WITH ADVANCED COMPUTING AND CONTROL
216. ENERGY SAVING IN THE FILTRATION AND DRYING OF COMPRESSED AIR
217. CUTTING ENERGY LOSSES THROUGH EFFECTIVE MAINTENANCE (TOTALLY PRODUCTIVE OPERATIONS)
227. HOW TO APPRAISE CHP. A SIMPLE INVESTMENT APPRAISAL METHODOLOGY
231. INTRODUCING INFORMATION SYSTEMS FOR ENERGY MANAGEMENT
238. HEAT RECOVERY FROM AIR COMPRESSORS
260. OPTIMISATION OF INDUSTRIAL PAINT AND POWDER COATING

Copies of these Guides may be obtained from:

Energy Efficiency Enquiries Bureau
ETSU
Harwell
Didcot
Oxfordshire
OX11 0RA
Tel No: 01235 436747. Fax No: 01235 433066. E-mail: etsuenq@aeat.co.uk

Overseas customers please remit £3 per copy (minimum of £6) with order to cover cost of packaging and posting. Please make cheques, drafts or money orders payable to ETSU.

FOREWORD

This Guide is part of a series produced by the Government under the Energy Efficiency Best Practice Programme. The aim of the programme is to advance and spread good practice in energy efficiency by providing independent, authoritative advice and information on good energy efficiency practices. Best Practice is a collaborative programme targeted towards energy users and decision makers in industry, the commercial and public sectors, and building sectors including housing. It comprises four inter-related elements identified by colour-coded strips for easy reference:

— *Energy Consumption Guides:* (blue) energy consumption data to enable users to establish their relative energy efficiency performance;

— *Good Practice Guides:* (red) and *Case Studies:* (mustard) independent information on proven energy-saving measures and techniques and what they are achieving;

— *New Practice projects:* (light green) independent monitoring of new energy efficiency measures which do not yet enjoy a wide market;

— *Future Practice R&D support:* (purple) help to develop tomorrow's energy efficiency good practice measures.

If you would like any further information on this document, or on the Energy Efficiency Best Practice Programme, please contact the Environment and Energy Helpline on 0800 585794. Alternatively, you may contact your local service deliverer – see contact details below.

ENGLAND

London
Govt Office for London
6th Floor
Riverwalk House
157-161 Millbank
London
SW1P 4RR
Tel 020 7217 3435

East Midlands
The Sustainable Development Team
Govt Office for the East Midlands
The Belgrave Centre
Stanley Place
Talbot Street
Nottingham
NG1 5GG
Tel 0115 971 2476

North East
Sustainability and Environment Team
Govt Office for the North East
Wellbar House
Gallowgate
Newcastle-upon-Tyne
NE1 4TD
Tel 0191 202 3614

North West
Environment Team
Govt Office for the North West
Cunard Building
Pier Head
Water Street
Liverpool
L3 1QB
Tel 0151 224 6401

South East
Sustainable Development Team
Govt Office for the South East
Bridge House
1 Walnut Tree Close
Guildford
Surrey
GU1 4GA
Tel 01483 882532

East
Sustainable Development Awareness Team
Govt Office for the East of England
Heron House
49-53 Goldington Road
Bedford
MK40 3LL
Tel 01234 796194

South West
Environment and Energy Management Team
Govt Office for the South West
The Pithay
Bristol
Avon
BS1 2PB
Tel 0117 900 1700

West Midlands
Regional Sustainability Team
77 Paradise Circus
Queensway
Birmingham
B1 2DT
Tel 0121 212 5300

Yorkshire and the Humber
Sustainable Development Unit
Govt Office for Yorks and the Humber
PO Box 213
City House
New Station Street
Leeds
LS1 4US
Tel 0113 283 6376

NORTHERN IRELAND
IRTU Scientific Services
17 Antrim Road
Lisburn
Co Antrim
BT28 3AL
Tel 028 9262 3000

SCOTLAND
Energy Efficiency Office
Enterprise and Lifelong Learning Dept
2nd Floor
Meridian Court
5 Cadogan Street
Glasgow
G2 6AT
Tel 0141 242 5835

WALES
Business and Environment Branch
National Assembly for Wales
Cathays Park
Cardiff
CF10 3NQ
Tel 029 2082 5172

CONTENTS

Figures

Tables

1. INTRODUCTION

The purchase of a new paint curing or stoving oven is a substantial investment for your business. You will rightly expect many years of effective and efficient operation from the equipment that you buy. Therefore, choosing the right oven for your needs is important.

Most companies in the engineering industry purchase a new oven only infrequently, and therefore do not have the opportunity to develop detailed knowledge of the range of ovens available. Often the only source of information available to you is from your existing oven supplier. This **independent** Guide draws together the experiences of a wide range of oven suppliers and, crucially, oven users like yourself.

The first step in selecting the best oven for you is to identify the main selection criteria. The main issues that you will consider when choosing an oven will include:

- production rate;
- operating profile, e.g. continuous production of identical components or batch-wise production of varied components;
- coating quality;
- preferred paint system;
- capital cost;
- maintenance requirements;
- level of operator skill and intervention required.

It is also important that health and safety and environmental issues are considered. Emissions of solvents to the atmosphere must comply with any legal limits set by the regulatory authorities. Similarly, concentrations in the workplace must be below specified Occupational Exposure Limits. Other safety and environmental issues to consider include access for operation and maintenance, flammability limits and noise.

In addition, this is **an ideal opportunity to reduce your energy costs**.

Paint curing or stoving is one of the largest consumers of energy in the engineering industry. Therefore when designing or specifying new paint curing or stoving ovens you can make a significant contribution to your site's overall energy efficiency by carefully selecting the most appropriate oven.

The annual operating costs will be a significant element in the total lifetime cost of the oven. You must therefore consider energy efficient designs in your selection process to identify the option with the lowest total 'annualised' costs (see Section 6.2) that achieves your performance and operability requirements.

The aim of this Guide is to help you to specify the oven for your particular application that will minimise your energy costs.

It will help you to do this by identifying the important energy and operating cost issues and how they can be reduced. This will enable you to question your suppliers to make sure that you get the best oven for you.

The basic process to identify the best oven for your needs is illustrated in Fig 1 and discussed in the following sections.

Section 2 identifies the areas in which you may be able to save energy. This will help you to make informed decisions about the oven type and design features you need to specify to make the greatest energy savings.

Section 3 presents guidance on oven selection. The main types of oven, including their typical applications, advantages and disadvantages, are discussed. The use of a combination of techniques to improve energy efficiency is also discussed in this section, as are emerging oven technologies.

Section 4 presents a range of oven design features that have an important influence on energy efficiency. There are also examples of cost savings that demonstrate what has been achieved as a result of adopting these features on existing ovens.

Section 5 discusses how to install, commission and operate your oven to ensure energy running costs are kept to a minimum.

Section 6 demonstrates how to evaluate the total lifetime cost of an oven by taking into account the operating costs as well as the initial capital cost.

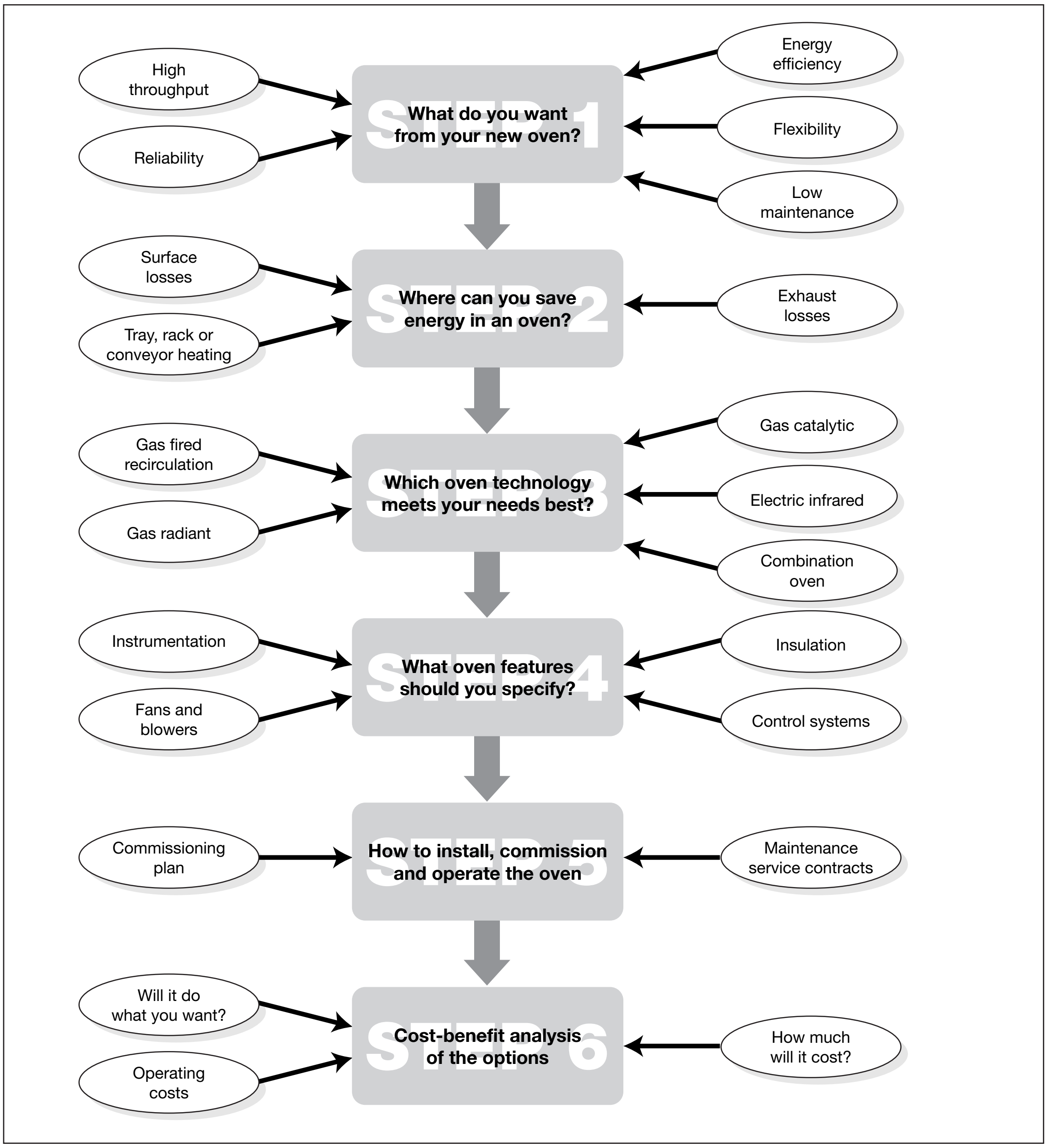

Fig 1 A stepwise approach to lower energy costs

2. WHERE CAN YOU SAVE ENERGY?

It has been estimated that the energy used in paint curing and stoving ovens costs the engineering industry more than £100 million per year. These costs can be reduced by specifying an energy efficient oven. You may not have considered energy efficiency before; therefore you may not realise that most of the energy used in an oven is lost as waste heat.

Natural gas and electricity are most commonly used to provide heat. Only a small amount of this heat input is used to heat and cure the coated product items.

Did you know that the energy used to heat and cure the products is only:

- 5-10% of the total energy consumed for gas fired air recirculating ovens;
- 15-20% of the total energy consumed for infrared ovens.

Most of the heat input is lost:

- heating up the oven structure;
- heating up internal racks or conveyors;
- through the oven walls;
- in the oven exhaust;
- from open ends (tunnel ovens).

A typical energy balance for a gas fired air recirculation tunnel oven is shown in Fig 2.

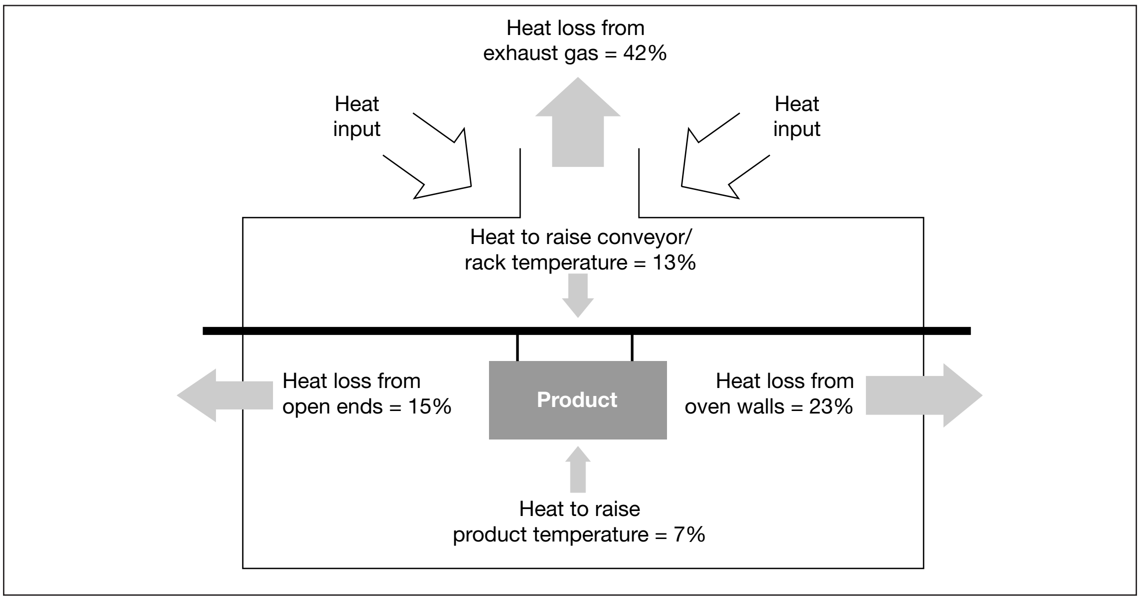

Fig 2 Typical energy balance of a tunnel oven

For a tunnel oven, heat losses from the oven wall and in the exhaust gases together can account for two-thirds of the total energy input.

A typical energy balance for a gas fired air recirculation box oven is shown in Fig 3.

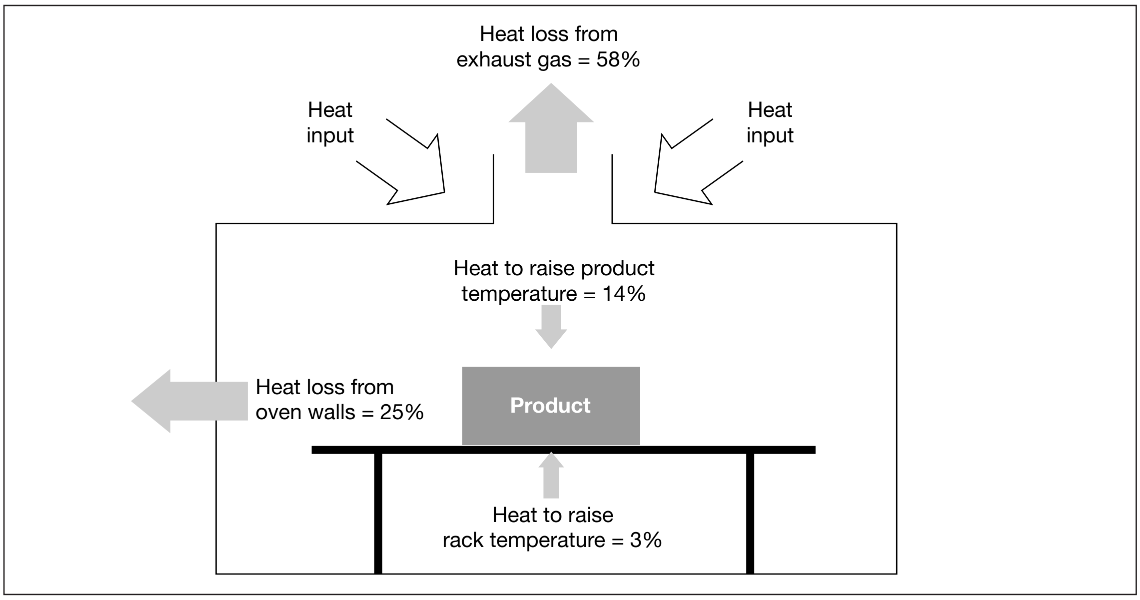

Fig 3 Typical energy balance of a box oven

For a box oven, heat losses from the oven wall and in the exhaust gases together can account for over 80% of the total energy input.

It is clearly important that the losses from the oven walls and in the exhaust gases are reduced as much as possible.

A full and rigorous understanding of how energy is used in your oven can only be gained through completing an energy balance. This calculates the heat inputs and the various heat losses. Fig 4 illustrates the steps and Appendices A - D explains how it can be done together with worked examples.

The relative advantages and disadvantages of different types of paint curing ovens, and their effect on energy efficiency, are presented in Section 3. **The type of oven selected has the greatest impact on the energy costs you will incur.**

To save energy and reduce the operating costs for the oven you select you should concentrate on the following areas:

- ratio of recirculation air to exhaust air (Section 4.1);
- heat input control system (Section 4.2);
- control of curing times (Section 4.3);
- thickness of panel insulation (Section 4.4);
- fans and motor specification (Section 4.5);
- design features e.g. air curtains for tunnel ovens (Section 4.6);
- conveyor design and product transport design (Section 4.7).

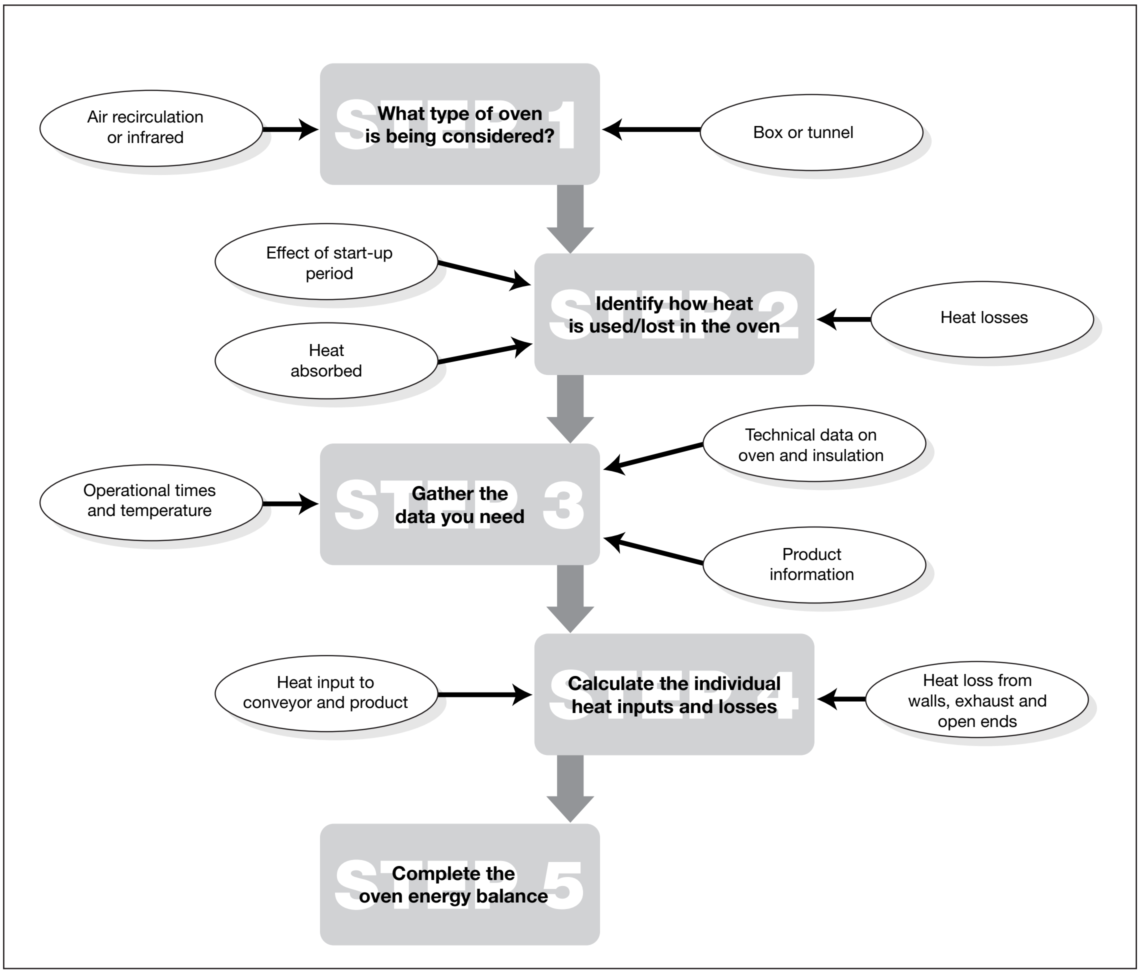

Fig 4 Performing a thermal energy balance

3. WHAT TYPE OF OVEN DO YOU NEED?

The type of oven selected has the greatest impact on energy costs, so it is important to make the right choice.

When choosing a new oven your initial thoughts are probably to select the same type that you already operate. However, there are several paint curing or stoving oven systems available on the market to satisfy a broad range of applications in the engineering industry. The best oven for you will depend on the criteria that are important to you:

- quality of product finish;
- curing speed;
- capital costs;
- reliability;
- ease of operation;
- maintenance requirements;
- operating costs.

3.1 The Effect of Paint Systems

In general, most paint systems can be cured successfully in all types of ovens.

Paint systems fall into three main categories:

Solvent Based
Traditionally, the industry has mainly used solvent based paints as these have provided a better finish to metal and plastic components. Many companies are now switching to water based paints or powder coatings to comply with environmental legislation. However, solvent based paints will be important for the foreseeable future as there are still applications where a suitable alternative is not available. Higher solids paints are being selected by many companies in preference to water based paints.

Water Based
Water based paints are becoming increasingly important as companies seek to comply with environmental legislation on VOC emissions. It is often thought that water based paints do not provide the coating quality required. However, applications and knowledge of water based paints are expanding rapidly. They are becoming more widely used and accepted, therefore it is worth consulting with paint manufacturers to discuss the latest developments.

It should be noted that, in comparison to solvent based paints, water based paints require a slower build up of paint on the component. In addition, the flash off time prior to curing is much longer. Water based paints can also be less resistant to corrosion.

Powder Coating
Powder coatings require much higher curing temperatures than solvent and water based paints. However it is not necessary to heat the whole mass of the components to the operating temperature to undertake the curing process. This should increase the energy efficiency of the curing or stoving operation. Manufacturers will provide paint application data sheets which give information on the curing times for the paint film (on different substrate materials).

You can obtain data on the optimum curing times and temperatures for particular paint types from oven manufacturers and paint suppliers. However, actual curing speeds will depend on a number of factors such as size, shape and weight of the component, paint type and colour, oven type and configuration and operating temperature. Table 1 gives typical oven times and operating temperatures in industry.

Table 1 Typical oven times and operating temperatures

Paint type	Oven time (mins)			Operating temperature (°C)
	Gas fired - air recirculation	Infrared systems	Ambient drying	
Water	10 - 30	1.5 - 6	> 60	50 - 120
Solvent	12 - 45	4 - 12	>120	50 - 150
Powder	20 - 55	6 - 14	n/a	160 - 200

Note: In applications where either water or solvent based paints may be used water based paints will usually take longer to cure, and hence use more energy.

3.2 Box or Tunnel Oven?

Any oven operated falls into one of two broad categories:

- box ovens, for batch curing operations;
- tunnel ovens, for continuous curing operations.

The first decision you need to make is between a box or a tunnel oven. There are two main factors you will have to consider.

Production capacity
For applications where product throughput is so low that a continuous curing operation throughout the shift is not required, you should probably select a box oven.

For higher throughputs, tunnel ovens should be considered if:

- you are operating a continuous coating process;
- the number or size of box ovens (and thus the cost) needed to do the same duty are excessive;
- batch curing is a bottleneck in the whole manufacturing process.

Flexibility
Box ovens provide greater flexibility of operation. Times and temperatures of cure can be varied with greater ease for small batch sizes. This is useful:

- where a variety of paint types will be used;
- where different types (size, substrate, mass etc.) of components will be coated.

Tunnel ovens are more suitable for longer product runs with a small number of different types of components.

3.2.1 *Box Ovens*
You should generally use box ovens for relatively low throughput, batch operations.

Box ovens operate on a batch-wise basis. There is significant heat input at both the heating up and the curing stages of the cycle. During **heating up**, energy is mainly used and lost in:

- raising internal oven structure and racking/trays from initial to operating temperature;
- raising products/components from initial to operating temperature;
- heat losses in oven exhaust;
- heat losses through oven walls.

During **curing**, energy is mainly lost in the oven exhaust and through the walls.

An example of a typical box oven is shown in Fig 5.

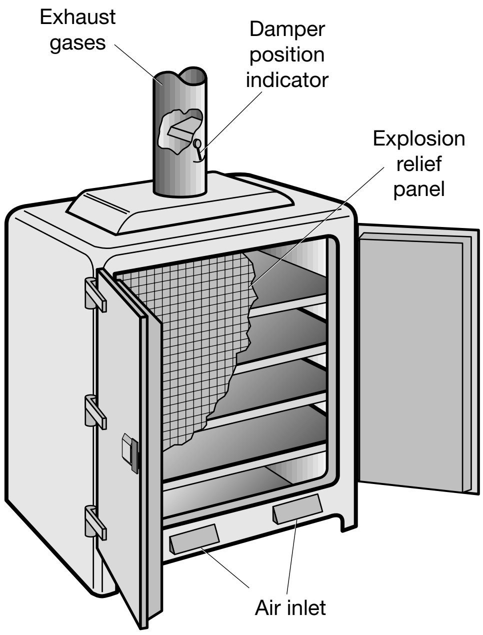

Fig 5 Typical box oven

3.2.2 *Tunnel Ovens*

You should generally use tunnel ovens for higher throughput processes. They are usually heated up from cold just once per shift or per day. They usually then run continuously and even if there is a break in production they are maintained at, or close to, operating temperature. An overhead conveyor is typically used to transfer products through the oven which has openings at both ends. An example of a conveyorised tunnel oven is shown in Fig 6.

Fig 6 Conveyorised tunnel oven

Another common type of tunnel oven is the camel back oven, as shown in Fig 7.

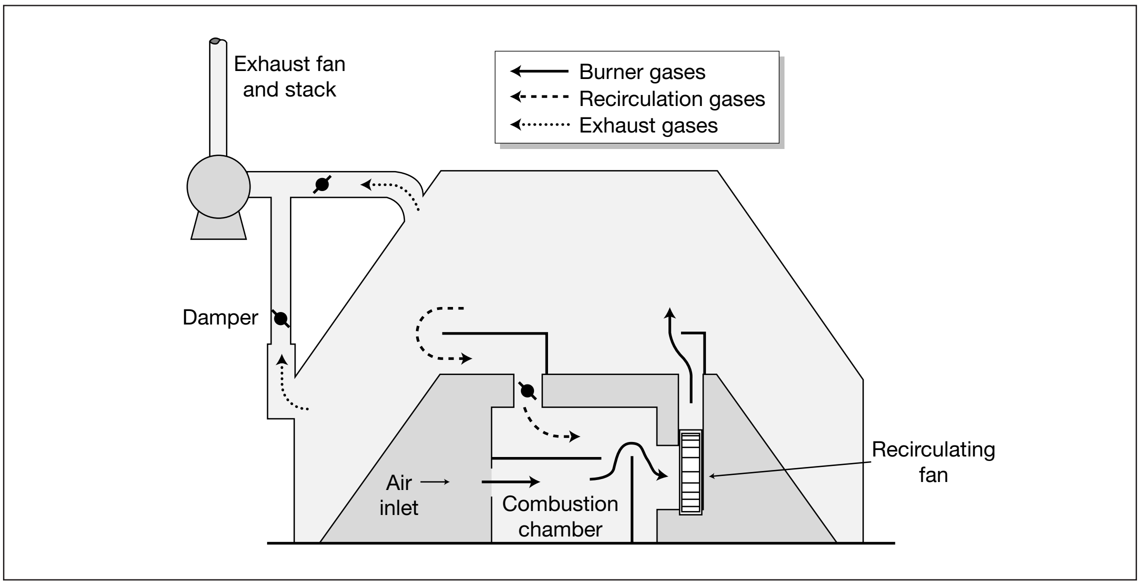

Fig 7 Typical camel back tunnel oven

An alternative design is the flat bed oven where components are laid on a slider bed. An example is shown in Fig 8.

Fig 8 Slider bed tunnel oven

3.3 Oven Types

You will also have to decide which oven technology is best for you. There are two basic heating methods:

- heating by convection - air recirculation heats the air in the oven, which in turn heats the components;
- heating by radiation - infrared heats the components directly.

There are variations of these two basic types and they can also be combined:

- air recirculation;
- electric infrared;
- gas radiant (infrared);
- gas catalytic (infrared).

The advantages and disadvantages of each are discussed below to help you make the right decision. Table 2 summarises the differences between the four oven technologies listed.

Table 2 Comparison of oven technologies

Oven technology	**Air recirculation**	**Electric infrared**	**Gas radiant (infrared)**	**Gas catalytic (infrared)**
Capital cost	L/M	H	H	H
Heat transfer efficiency	L/M	H	H	H
Curing speed	L	H	M	M
Curing of complex components	H	L	M	M
Oven set-up requirements*	L/M	H	M/H	M/H
Maintenance needs	L	H	M	M

* In some types of oven, particularly electric infrared, the distance between the heat source and the target is very important.
Key: L - Low, M - Medium, H - High.

3.3.1 *Air Recirculation Ovens*

a) Direct-Fired Air Recirculation Ovens

The most common types of ovens used in the engineering industry are gas and electric fired air recirculation systems. 'Direct' means that the air heated by the combustion of the fuel is in direct contact with the coated products. Indirect systems can also be used and are discussed later.

Heat is generated by combustion of gas in air in a burner box, or from an electrical element usually positioned above the oven. The hot air enters the oven to transfer heat to the product. Some of the exhaust air is recirculated back into the oven to reduce heat losses and energy consumption.

Natural gas is an excellent fuel as it can be mixed easily with combustion air and requires very little excess air in the mixture. Another benefit of using gas is that the rate of output of heat from a gas flame can be easily controlled by varying the flow rate of the gas or combustion air.

The applications for this type of oven cover the whole spectrum of paint curing and stoving. The majority of ovens used in the engineering sector, probably more than 90%, are direct-fired air recirculation ovens.

Advantages

- Curing can be carried out effectively for different sizes and shapes of components.
- An even distribution of heat, and therefore even curing is provided to the components.
- They can be used to cure all paint types.
- Maintenance costs are low.
- The unit cost of gas is low compared to other fuels, particularly electricity.

Disadvantages

- The speed of cure is slow as the heat transfer to the components is relatively inefficient (see Table 1).
- Start-up can take longer than other methods as the air in the oven has to reach operating temperature.
- Energy is used to heat all the air in the oven up to the operating temperature.
- The products of combustion can cause 'gas checking' of some paint finishes (the paint film has a rippled effect when fully cured).

An example of a direct-fired air recirculation box oven is shown in Fig 9.

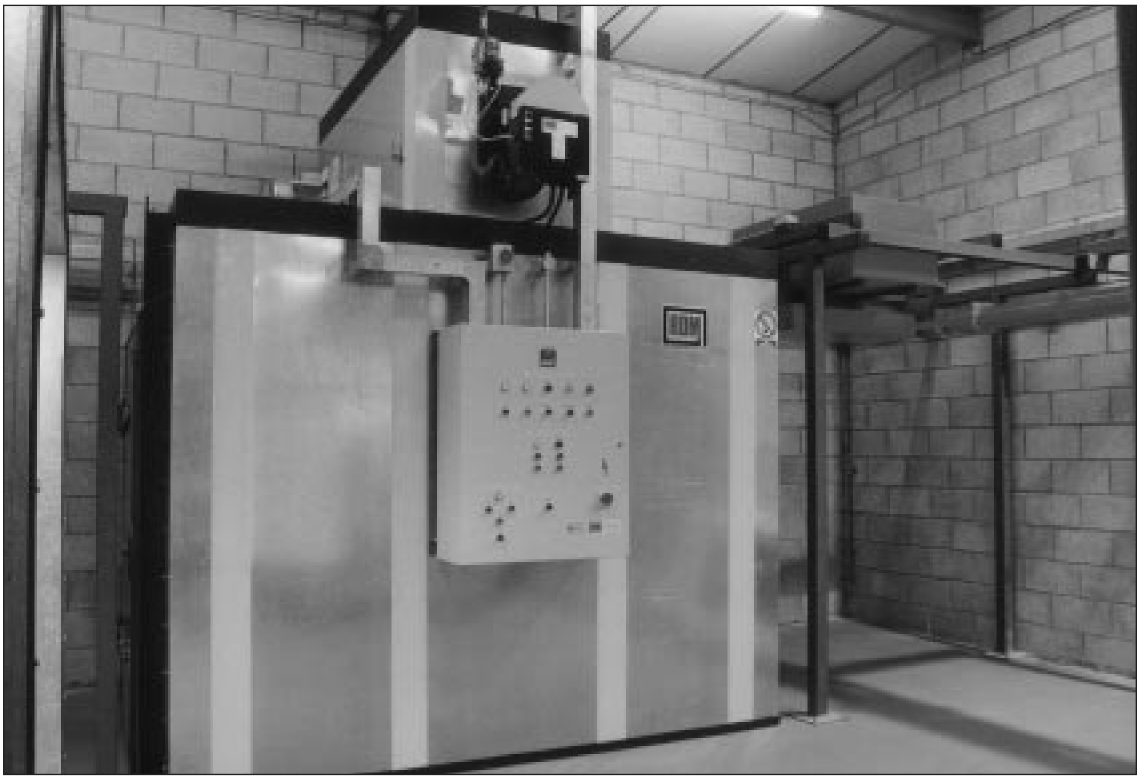

Fig 9 Direct-fired air recirculation box oven

b) Indirect-fired Air Recirculation Ovens

Here heat is transferred into the oven via a heat exchanger. Hot combustion gases/vapour transfer heat to the air in the oven through the heat exchanger. The hot air is then recirculated through the oven to heat the product or component that is to be cured.

This type of oven would be used if the heat source has to be kept separate from the product, e.g.

- steam - moisture could affect the curing;
- fuel oil - droplets or soot particles could spoil the finish;
- gas - products of combustion could spoil the finish, e.g. 'gas checking'.

Normally, you would only consider choosing an indirect-fired air recirculation oven if there is:

- a problem with finish quality on direct-fired ovens;
- no adequate mains gas supply to site;
- plenty of steam available (e.g. an on-site combined heat and power plant);
- waste heat available (e.g. thermal oxidiser exhaust gases).

Compared with a direct-fired air recirculation oven, an indirect-fired air recirculation oven is less energy efficient because of the heat lost in the heat exchanger.

In comparison with the full range of oven technologies, the advantages and disadvantages are similar to direct-fired air recirculation ovens.

3.3.2 *Electric Infrared Ovens*

These ovens use electric infrared emitters, either as a fixed arch or as mobile units positioned within the oven enclosure. Emitters consist of a series of tungsten filaments surrounded by quartz coverings. Each filament is also covered by a red quartz filter to reduce exposure to the higher spectrum of ultraviolet waves. Short and medium infrared waves are most readily absorbed by paints and are therefore most effective for curing.

Advantages

- Very fast paint curing can be achieved, due to the short wave infrared produced. This enables tunnel ovens to be shorter or production speeds to be faster.
- Efficient transfer of heat from the radiation source to the paint. The air within the oven does not absorb or block the radiated heat and therefore is not raised to the curing temperature.

Disadvantages

- Capital costs can be high.
- Electricity is an expensive fuel.
- The emitters heat ‘what they see’ such that ‘blind spots’ can occur with complex component shapes causing uneven curing.
- The distance from the emitters to the component is critical for effective curing. An emitter placed too close to the component will cause ‘popping’ and an emitter too far from the product will result in under-curing, or softness, in the paint finish.
- Curing can be less effective for some paint colours, particularly light coloured paints which can reflect some of the infrared waves.
- Maintenance costs can be high, i.e. the replacement of emitters.

Fig 10 Mobile electric infrared panels

3.3.3 *Gas Radiant Ovens*

Gas radiant ovens are made up of a series of panels positioned in the oven walls. The panels are usually a permeable ceramic material housed in a stainless steel structure and a gas/air mixture is ignited on the surface of the ceramic material. The high temperature radiant burner produces radiated heat waves that cure the coated components passing through the oven. Fig 11 shows a gas radiant oven.

Fig 11 Gas radiant oven

Advantages

- Rapid curing speed. Gas radiant ovens produce medium wave infrared which, whilst not curing as quickly as short wave infrared, is much more rapid than air recirculation ovens (see Table 1).
- Efficient transfer of heat from the radiation source to the paint. The air within the oven does not absorb or block the radiated heat. Some natural convection occurs. If the burner panels are contained in polished stainless steel housings, the infrared waves are reflected and re-used. This means that gas radiant ovens are more effective than electric infrared ovens at curing components with complex shapes.
- The tiers of top and bottom panels can be adjusted through 45 degrees to allow the energy profile to suit the size and configuration of the components, while doors at both ends can reduce the heat loss.
- Operation of individual panel burners allows the heat input to be controlled.

Disadvantages

- Capital costs can be high.
- The distance from panels to the product is critical and can be restrictive when a product line is changed over. However oven designs can incorporate adjustable panels which allows for flexibility.
- Ovens with mobile burner panels do not generally have insulated floors which causes greater heat losses.
- Maintenance costs can be high, i.e. cleaning and replacement of ceramic panels.

M & R Refinishing in Nottingham has recently replaced an old electric infrared oven with a new gas radiant oven. The previous electric emitters were very delicate and had to be replaced frequently, amounting to significant maintenance costs. With no gas supply to the site, the company has selected the oven to run on liquid petroleum gas (LPG) fuel. LPG tanks were installed on-site free of charge and the oven has been in operation since 1997. So far the new oven has incurred negligible maintenance costs. The energy cost savings compared with the previous system are estimated to be £7,000/year.

3.3.4 *Gas Catalytic Ovens*

Gas catalytic ovens transfer heat by radiation, although some transfer also occurs by convection. The emitters used in gas catalytic ovens produce short to medium wave infrared. An electrical element pre-heats a catalyst fibre pad, gas then enters the back of the pad and is dispersed through it, mixing with oxygen from the air. A catalytic reaction then takes place which produces infrared energy. Fig 12 shows a gas catalytic oven.

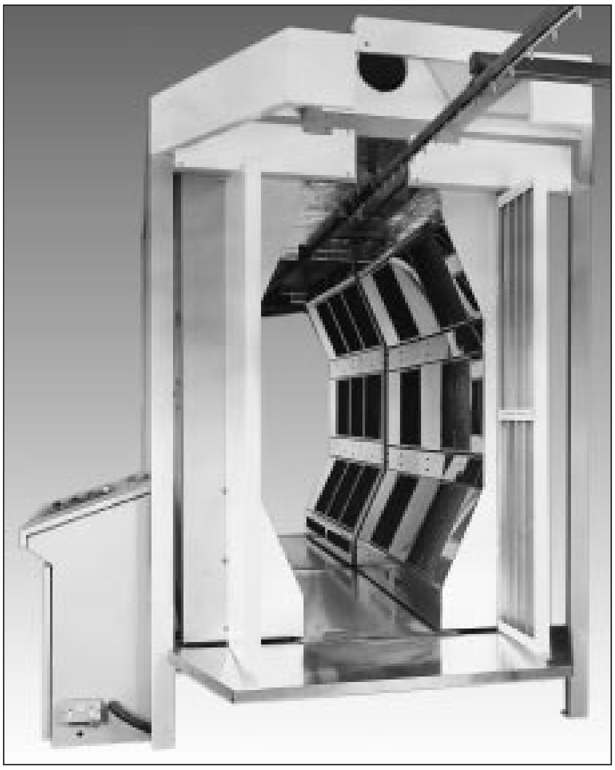

Fig 12 Gas catalytic oven

Advantages

Similar to gas radiant ovens.

- Rapid curing speed.
- High efficiency of heat transfer from the heat source to the paint.
- More effective than electric infrared ovens at curing components with complex shapes.
- Adjustments can be made to the panels to reduce the width of the oven to accommodate different sizes of components.
- The catalytic reaction does not require a flash off period before start-up. The catalytic reaction can be enhanced by any solvent laden air present in the oven.

Disadvantages

- Capital costs are high.
- Catalyst may be poisoned over a prolonged period and therefore the maintenance costs can be significant.

3.3.5 *Combining Technologies*

A current development is to combine different technologies in a single oven unit. These combination ovens try to maximise the benefits of:

- heating by convection (recirculation ovens), i.e. high quality curing with all types of coatings on any product or component;
- heating by radiation (gas radiant, gas catalytic, electric infrared), i.e. more rapid curing, which increases production capacity or reduces oven size, and has greater energy efficiency.

Examples of a combination oven include convection heat combined with radiative panels. Other systems include infrared arches positioned within an air recirculating oven allowing for the flexibility of operation.

Infrared as pre-heat
Tunnel ovens can use an infrared pre-heater to get the components quickly up to temperature before they pass into the air recirculation section of the oven. The conveyor speed is adjusted to ensure that the components are in the oven for an optimum curing time. This type of oven system can reduce the operating costs and the oven size significantly, compared with a traditional air recirculation oven.

> Bisley Office Furniture in Newport carries out the continuous spraying and curing of a variety of components in tunnel ovens consisting of a small infrared pre-heat section followed by a gas fired air recirculation system. The components are quickly heated up in the infrared section and are close to the curing temperature before entering the air recirculation section. This allows the overall oven size to be reduced significantly, which was important as floor space was at a premium. In addition, the infrared pre-heat section causes the powder coating to adhere the components. This has reduced the amount of powder that is blown off the components on entry to the air recirculating system, which in turn has reduced the reject rate of unevenly cured components.

3.4 Emerging Technologies

There are other paint curing and stoving oven technologies that are being developed. Although these are not in common use at present, they may become increasingly important in the future. A number of these emerging technologies are discussed briefly below.

Microwave Heating
Microwave heating for paint curing is being actively developed. One promising technique is known as ‘Variable Frequency Microwave’ energy (VFM). This technique has overcome the problems associated with earlier microwave technology, i.e. non-uniform heat distribution, hot spots and overheating of the paint. It is now considered to be a viable technology for paint curing and stoving operations.

Induction Heating
Painted components can be cured by the heat produced by induction in an electromagnetic coil. The painted components are passed through a copper coil which generates electromagnetic waves which in turn generates heat by conduction within the component. The paint is therefore cured from inside to outside.

Typical applications for induction heating include components that are narrow and thin, such as steel pipes. The potential advantages for induction heating include an extremely high heat transfer efficiency and speed of curing. The disadvantages of this method are the restriction of the size and shape of components that can be cured. In addition there has to be careful control of the heat source to ensure that there is no damage to the paint finish.

> One company has selected induction heating as its preferred method of curing for the bolts it coats. A short conveyor is used to pass the powder coated components through a magnetic field which is generated by a 1 m long coil. The benefits of this system have been the very short heating times, the small ‘footprint’ of the curing process and considerably lower operating costs.

Ultraviolet Heating

Ultraviolet (UV) is currently being used for drying/curing inks, lacquers and adhesives in industries such as the packaging, printing, compact disc manufacturing, electronics, wood, paper, metal and glass. UV curable powder coatings are now available. Applications include powder coating applied to MDF and plastics in which the powder is first melted with infrared and then UV cured. Research is ongoing by paint manufacturers to develop paints that are suitable for curing with UV lamps.

3.5 Selection Guide for Different Oven Types

Table 3 Selection guide for different oven types

	Import-ance	**Type of oven**					
		Air recirculation		**Electric infrared**		**Gas radiant and catalytic***	
How important is it for you to	**Score**	**Factor**	**Score**	**Factor**	**Score**	**Factor**	**Score**
Minimise capital cost?		2		1		1	
Maximise energy efficiency?		1		3		3	
Cure rapidly?		1		3		2	
Cure complex shapes?		3		1		2	
Cure different shapes and sizes easily?		3		1		2	
Minimise maintenance costs?		3		1		2	
Oven Score							

* Further detailed investigation is required before a choice can be made between gas radiant and catalytic ovens.

To identify which is the best type of oven for you:

1. Identify which are the most important issues for you.
2. Give each issue an **Importance Score (1 = low, 2 = moderate, 3 = high)**
3. For each type of oven, multiply the **Factor** by the **Importance Score**
4. For each type of oven, add up the individual **Scores** to produce a total **Oven Score**
5. The highest **Oven Score** indicates the type of oven that best meets your requirements.

If you have requirements that seem to be in conflict, e.g. rapid curing and complex components, consider a Combination Oven.

Contact oven suppliers to discuss your application in more detail.

4. SELECT THE OVEN FEATURES

Once you have selected the type of oven you want, you need to consider what features the oven should have.

These are the instruments and equipment that will enable you to operate the oven effectively and efficiently. If you specify the correct oven features, your oven will produce excellent quality finishes and be energy efficient. The most important features are:

- control of airflow;
- control of heat input;
- control of drying and curing times;
- carcass material and insulation;
- drives and fans (motor efficiencies);
- design of product racks, trays or conveyors.

The features of ovens are discussed below. The first points are those that are the minimum requirements you should aim for. Also listed are issues, additional benefits and options that should be considered.

4.1 Control of Airflow and Fans

As a minimum	- *Aim to recirculate as much air as possible within the oven.* - *Discuss options for air distribution with manufacturers.*
In addition, consider	- *Air flow sensors that measure how well the flows within the oven are balanced.*

> An energy efficient air recirculation oven will typically recycle 90% of the air within the oven.

Some air has to be exhausted from most ovens to:

- ensure oxygen is present for combustion;
- remove products of combustion;
- ensure solvent concentrations do not exceed 25% of the solvent Lower Explosive Limit (LEL).

The exhaust flow should be high enough to satisfy these requirements, but no more. Excessive exhaust flows waste energy and cost money.

> Rule of thumb:
>
> If an oven operates for 2,000 hours/year (8 hours/day, 5 days/week, 50 weeks/year), then for every 10 m^3/hour of exhaust flow the energy losses and costs are approximately:
>
> - @ 50°C 150 kWh (£8/year)
> - @ 100°C 400 kWh (£20/year)
> - @ 150°C 600 kWh (£30/year)
> - @ 200°C 750 kWh (£38/year)

4.2 Control of Heat

As a minimum:	- *Use a high/low burner control system.* - *Position the thermocouple carefully to monitor the oven operating temperature, e.g. not too close to the burner flame.* - *Use pyrometers for temperature measurement in infrared ovens.*
In addition, consider:	- *Installing proportional integral device (PID) burner control systems.* - *Installing multiple thermocouples at different points within the oven.* - *Asking the oven supplier the temperature range around the operating set point. A range of ± 5°C is typical, but a narrower range improves both product finish and energy efficiency.*

4.2.1 *Burner Control*

Various control systems can be used to control the operation of the burners within the oven.

- An on/off control system will maintain the operating temperature within the oven by the burner being switched on and off continuously.
- A high/low control system controls the operating temperature by the burner switching between high and then low burn.
- A PID programmable controller has the fastest and most accurate response for controlling the burner. Its responsiveness means it is also the most energy efficient of the controls.

> A PID controller may cost £200 - £500 more than a high/low control system. The higher capital cost of the oven system should be balanced against the potential saving of 5% in operating costs.

4.2.2 *Temperature Control*

The number and placement of thermocouples within the oven chamber will be important for accurate temperature measurement and response to changing temperature profiles. Preferably more than one thermocouple should be used to control the temperature. The thermocouples should be placed evenly within the oven. You should consult the oven manufacturers to decide on how many thermocouples you need and where they should be positioned. Thermocouples should be placed in the top section of the oven, ideally at the return air duct before redistribution back into the oven.

> There should be at least one thermocouple per burner/fan assembly positioned in the top of the oven away from the flame.

You should also have an 'over' temperature thermostat or a 'policeman' controller which acts as an override if the main temperature controller fails. Additional information can be obtained from GPG 215 *Reducing Energy Costs in Industry with Advanced Computing and Control*.

Some tunnel ovens maintain temperature profiles in the oven by separate measurement and control of the different zones. A tunnel oven that has different temperature zones will have to be controlled with at least one thermocouple per temperature zone.

The temperature of an infrared system is measured by a pyrometer, which is a non-contact thermal sensor that can read the surface temperature of the component. A signal is then sent back to the control system and the heat energy being radiated towards the component is controlled as necessary.

Combination ovens can have control valves and switches for individual gas burners and infrared emitters. These can be pre-set, depending upon the throughput of components.

4.3 Control of Drying/Curing Time

As a minimum:

- *Include an adjustable process timer for box ovens.*
- *Include a speed controller for the conveyor in tunnel ovens.*

In addition, consider:

- *Discussing the optimum set up of curing time and temperature with both the oven and the paint suppliers*
- *Installing air blowers to speed up the curing of water based paints.*

The control of drying for a tunnel oven is mostly determined by the speed of the conveyor which feeds the products through the oven.

Box ovens control the curing time by means of an adjustable process timer. The timer switches the oven onto bake mode once the operating temperature has been reached. The timer will be set according to the product being cured in the oven. When the time expires the burner and fans shut down and an audible alarm will indicate to the operator that the bake cycle has been completed.

Curing of water based paints

Air blowers are increasingly being used to speed up the curing of water based paints. The ovens have a series of air jets that blow air over the painted components. The system is not suitable for solvent paints or powder coatings. The inlet air requires filtration to ensure no particulates settle on the coating. Other techniques that have been used to increase the curing speed of water based paints include increasing the air recirculation rate at the 'flash off' stage, prior to the bake stage.

Condensation units are now also being used to improve the curing time of water based paints. Water vapour in the air is removed before being recirculated back into the oven. This provides a driving force for improved flash off and cure.

> RCM Bendate Motors has recently acquired a new combination spray/bake box oven for its repair/refinish works in Liverpool. The oven is a gas fired air recirculation system fitted with air jets to blow ambient air towards a product and speed up the drying time of water based paints. This is considered to be a particularly cost effective method for water based paints that the company is using in increasing quantities. For resprays using solvent based paints, the air jets are switched off.

4.4 Carcass Material and Insulation

When considering the construction of the oven:

As a minimum:

- *Check that auxiliary equipment (fans, burner boxes) is insulated.*
- *Check that metal to metal contact is minimised.*
- *Insulation should be at least 100 mm thick*

In addition, consider: - *Installing polished steel internal surfaces to reflect heat.*

> For an oven system that has been well insulated an operator should be able to touch the walls and not feel any discomfort. This improves both safety and energy efficiency.

Ovens are typically constructed of a heavy structural steel frame with insulated walls and door panels. The panels are typically a galvanised steel inner skin and mild steel outer skins with insulation material in between. Stainless steel oven linings can give greater corrosion resistance, as well as reflecting heat to improve energy efficiency.

Insulation performance depends on both the density of the insulation material and its thickness. The selection of the thickest mineral wool insulation will obviously minimise the heat loses from the oven walls. Mineral wool insulation is the most commonly used. Other insulation materials include ceramic fibre, strongboard or PVC cladding. Investigate the economic thickness of insulation.

> Rule of thumb: Increasing the insulation thickness of an oven from 75 mm to 100 mm will reduce the heat losses from the oven wall by about 25%.

4.5 Drives and Fans

As a minimum:
- *Check fans and motors are sized correctly for the duty.*
- *Specify higher efficiency motors.*

In addition, consider:
- *Specify dual or variable speed motors where the process load varies.*
- *Check the most cost effective cable size for power supplies.*

Specification of the correct fan size for a particular load is important as an oversized fan will incur higher running costs. Fans with higher efficiency motors have been shown to reduce operating costs significantly over a 10 year life. **The efficiency of a motor is very important because the electricity costs over its life far outweigh the initial capital cost.**

A higher efficiency motor is the most cost effective choice. They cost the same as a quality standard motor, and the extra purchase cost compared with cheap imported motors will easily pay back over the motor’s lifetime in reduced electricity consumption. Further information can be obtained from GPG 2 *Energy Saving with Electric Motors and Drives (Revised)*.

Dual (high/low) speed motors can be used for processes in which there might be two loads. This could be applicable to a spray booth/paint curing oven or a ‘combi’ booth in which there could be two different extraction rates for the spray and bake mode. Another option might be the use of an electronic inverter for speed control of fans.

4.6 Tunnel Oven Features

As a minimum:	- *Specify ovens designed with 'air curtains'.*
In addition, consider:	- *Installing ovens with a variable and reflective 'silhouette' door.*

Tunnel ovens have open ends, which means potentially large heat losses can occur due to the temperature difference between the oven and ambient surroundings. An 'air curtain' ensures that hot air is kept in the oven. A centrifugal fan is used to blow recirculation air through slots at the opening of the tunnel oven. A small proportion of ambient air is also drawn in from outside of the oven.

> For a tunnel oven with 'air curtains' that are designed and balanced properly, an operator should be able to stand close to the open ends without feeling any significant heat.

A variable silhouette door will improve the energy efficiency of the tunnel oven by reducing the area of open ends of the tunnel oven. The adjustable doors should be constructed of reflective material.

4.7 Conveyor Design and Product Transport Design

As a minimum:	- *Specify material for the conveyor and racks of low thermal conductivity.*

It is important to consider the design of the conveyor and rack system. The mass of the conveyor and rack system will absorb substantial amounts of heat. For box ovens, a lightweight rack frame should be used if available. For batch operations that involve curing components of different sizes, the rack should match the size and shape of the component.

4.8 Other Features

- Combi-booths used for spray/bake operations can have interlocks on the internal lights, so that they are switched off during the baking cycle, when operators are not paint spraying in the oven. Over the life of an oven, electricity savings will be achieved by adopting this feature.
- Some ovens now use heat recovery from exhaust thermal oxidisers fitted on the exhaust. The thermal oxidiser burns the solvent laden exhaust air and a heat exchanger then recovers some of the heat in the exhaust gas for use in the oven.

4.9 Checklist

The following is a checklist of the important issues which you should discuss with oven manufacturers. This will enable you to raise all the relevant issues to help ensure you end up with the most energy efficiency oven to meet your needs.

Energy Efficiency Checklist For Discussion With Oven Suppliers

Control of Airflow

- ☐ How can I maximise the recirculation rate of air?
- ☐ Would airflow sensors in the oven be cost effective?

Control of Heat

- ☐ Would an advanced (PID) control system for heat input be beneficial?
- ☐ How many thermocouples/pyrometers are included and where are they located?
- ☐ How tightly can the temperature be controlled (greater than ±5°C)?

Control of Drying/Curing Time

- ☐ Can you help me to optimise the curing time (for coating quality and energy efficiency) for the oven?

Carcass Material and Insulation

- ☐ Would increasing the insulation thickness of oven wall be cost effective?
- ☐ Is auxiliary equipment (e.g. fans) insulated?

Drives and Fans

- ☐ Should dual or variable speed drives or high efficiency motors be specified for this oven?

For Tunnel Ovens

- ☐ How can the losses from the tunnel oven open ends be minimised?

Photocopy this checklist and use it as an aide-memoire during discussions and meeting with potential oven suppliers.

5. INSTALL AND RUN THE OVEN

5.1 Installation and Commissioning

Before an oven system is installed on-site you should ask the oven manufacturers to set up the oven and carry out trials at their own premises. This may involve placing painted products into ovens to confirm the curing time required and thereby optimising the oven configuration and, for tunnel ovens, the conveyor speed. If practicable the oven system should be pre-assembled, wired and tested prior to despatch from the manufacturers. Setting up the oven correctly in the first place is crucial if it is to be energy efficient in operation.

There are a number of important checks you should make whilst your oven is being installed, to ensure it will be energy efficient in operation.

Insulation. Check that insulation of the type, grade and thickness that you specified is installed.

Prefabricated panels. Ovens can be constructed from prefabricated modular panels to help make assembly and installation easier. Large heat losses can occur from the joints between panels if the construction and erection of the oven are not carried out correctly.

5.1.1 *Optimising for Energy Efficiency*

Commissioning of a new oven must test that all equipment and instrumentation works. However, you should also ensure the commissioning phase is used to optimise the oven set-up for finish quality, product throughput **and** energy efficiency. In particular, you should ensure that the following issues are addressed.

Combustion air. The correct air-fuel mixture is important. Too little combustion air will result in incomplete combustion. Too much air will reduce energy efficiency, as the excess will have to be heated up to the oven operating temperature.

Air recirculation. The amount of air recirculated within the oven should be maximised using dampers to control the air flows. The lower the exhaust flow, the higher the energy efficiency. However, the exhaust has to be sufficient to maintain efficient combustion and to keep solvent concentrations to below 25% of their Lower Explosive Limit (LEL).

> Example: A company uses an electric air recirculation oven with an exhaust gas flow rate of 500 m^3/hr. The company decides to investigate the level of VOC concentrations present in the oven during the bake cycle. The VOC concentrations in the oven are shown to be well below the LEL. Based on these findings, it is decided to recommission the oven. The air recirculation rate is increased enabling the exhaust gas flow rate to be reduced to 250 m^3/hour. This reduction in air flow rate represents a saving of over £3,000/year in heating costs.

Conveyor speed. Optimising the conveyor speed for tunnel ovens will maximise throughput whilst ensuring that an excellent coating finish quality is achieved.

Balancing air flows. Air flows within the oven should be balanced, using dampers, during commissioning. You should be able to stand next to the open end of a tunnel oven and, if it is correctly balanced, not feel a significant temperature increase.

Once the plant has been fully commissioned the operators will require training in how to operate the oven systems efficiently and effectively.

Servicing contracts with the oven supplier are valuable to ensure the performance of the oven is checked and optimised regularly, e.g. six-monthly.

5.2 Start-Up and Shut-Down Operating Procedures

It is important that ovens are started up only when they are needed and not automatically switched on first thing in the morning. Make sure ovens are only switched on when they are needed for the daily production schedule.

If you have a box oven, automatic start-up is initiated from a control panel located outside the oven. The burner and extraction fans will start up and when the oven reaches the operating temperature an audible timer should indicate that the ovens are ready for loading.

The start-up stage for tunnel ovens is also often automated and sequenced. If you have tunnel ovens you may have a control room with an operator to monitor start-up and shut-down of the ovens. During breaks your operators should turn down the burner to a low fire burn if possible. Turning the oven off completely may not be economical because the heat up period of ovens can last up to 30 minutes.

The shut-down process usually requires the extraction fan to be left on for a few minutes to purge any solvents from the oven.

5.3 Performance Optimisation Tools

After an oven has been operating for a while, its optimum performance can be reduced significantly. For example, this may occur if the burner becomes partially blocked or vibrations cause the dampers to move from their original positions. It is therefore important for your oven to be monitored and optimised regularly.

You should consider checking the performance of your oven once it has been in operation for a few months. You could do this by:

- asking your oven supplier to check the set-up and operation of the oven;
- consulting your paint suppliers, and compare operating experience with their advice on curing times and temperatures;
- preparing an energy balance for your oven (see Appendices A - D);
- undertaking a thermal imaging survey to identify where heat is being lost from oven walls, Fig 13 illustrates the heat losses from a poorly constructed oven.

Data loggers are useful tools for recording data on the temperature profile of ovens. They can be used during commissioning or to monitor existing plant. Thermocouple pins or clips are attached to the product to record the surface temperature which is then placed in the oven. Temperature measurements can also be taken at several locations in the oven.

Once your oven has been in operation for a while it is essential that you carry out temperature profiling regularly, particularly when using new sophisticated coatings. This is the only way to ensure that you achieve the quality of coating finish you require. It is not possible to check effectively during production that a coating has been fully cured. ‘Solvent rub’ tests are sometimes used but these can remove the gloss from a coating finish.

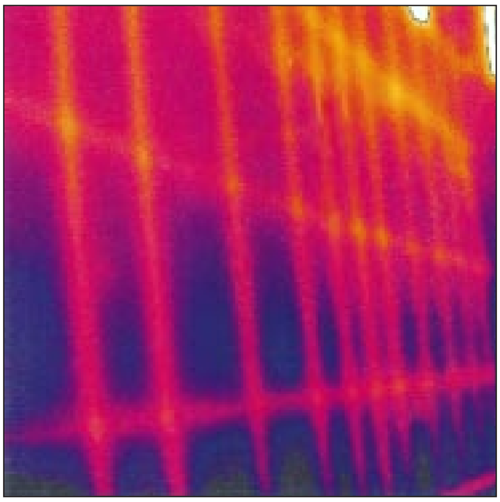

Fig 13 Heat losses from the outer skin of the oven, showing greater heat loss from the panel edges

Software is available that can provide analysis and manipulation of recorded data. For a company that changes the painted products regularly, data loggers can be a useful tool for determining the curing time required for new products. Alternatively, data loggers can be used to record the performance of the oven over a period of time. The potential benefits include improved quality and productivity as well as reduced fuel costs.

5.4 Site Routine Maintenance Checks

Simple checks can reveal poor oven operation and highlight potential problems. You should include the following checks into a routine maintenance procedure for the oven.

- Carefully touch oven walls, especially at panel joints. The temperature should be low enough to cause no discomfort.
- Carefully stand by tunnel open ends. The temperature should be low enough to cause no discomfort. Hot air should not be blowing out of the oven ends.
- Visual check of excessive air movement (i.e. work piece swinging).
- Consider purchasing data logging equipment so you can perform temperature profiling throughout the oven (important for quality). This equipment will cost approximately £2,000 to purchase or £100-£500/week to hire.

5.5 Suppliers' Periodic Maintenance Checks

Many oven suppliers offer an ongoing maintenance service that will typically involve site visits at six-monthly intervals. You should consider arranging a service contract for your ovens. To ensure your oven continues to operate in an energy efficient manner, you should ask for the following checks to be included in the maintenance service:

- damper positioning (for air recirculation ovens) and air flows;
- combustion efficiency (burners should be optimised);
- temperature profiles (tunnel ovens in particular);
- integrity of thermal insulation;
- correct operation of control systems and instruments.

6. WHAT ARE THE COSTS?

Whilst at first glance you may think certain energy efficient designs may be more expensive than traditional designs, when you develop the total annualised costs you may find the benefits of reduced energy bills in the long run outweighs a higher initial cost. Furthermore, some of the new designs may yield product throughput or quality benefits through more efficient curing techniques or better control of the curing process. These benefits should also be considered in the cost evaluation.

When choosing between different curing ovens, companies often only think of the initial capital cost of the oven rather than the total annual cost including both 'one-off' and operating costs. This section outlines a method of developing a total 'annualised' cost that can be used to compare options and help ensure that the most cost effective option is chosen.

Although capital and operating costs are funded from different budgets, the calculation of the annualised cost can argue the case for more authorised capital.

The total annualised cost can be calculated by expressing any one-off costs as a cost per year over the expected lifetime of the oven. Use the following simple equation:

Total annualised cost = Annualised 'one-off' cost + Annual operating costs – Annual benefits

These costs are explained below:

6.1 Annualised 'One-off' Cost

The 'one-off' cost will include all of the costs involved in:

- equipment purchase (include instrumentation and control systems);
- preparation of site and modifications to utility supplies;
- equipment installation;
- general project implementation.

Simple method

The simplest way to calculate annualised one-off costs is to divide the total one-off expenditure by the projected number of years of useful life of the oven. This is appropriate for quick calculations, but it does not allow for the fact that the true value of money will be worth less in future years than the face value today.

Therefore for an oven costing £100,000, over 10 years, the annualised one-off costs are £10,000/year.

Improved Method for Calculating Annualised 'One Off' Cost

The cost of capital can be taken into account by calculating an 'annualisation factor'. This factor, when multiplied by the one-off cost, will enable a more accurate annualised one-off cost to be calculated.

The annualisation factor can be calculated from the following equation:

$$\textit{Annualisation factor} = \left[\frac{r}{(1 + r)^n - 1}\right] + r$$

n is the lifetime of the oven in years

r is the discount rate fraction (this is the discount rate as a percentage, divided by 100).

You should use the rate of return used for investments within your company as the discount rate.

For example, an oven lifetime of 10 years and a discount rate of 10% gives an equivalent annualisation factor of 0.163:

$$\left[\frac{r}{(1 + r)^n - 1}\right] + r = \frac{0.1}{1.1^{10} - 1} + 0.1 = 0.63$$

Hence for a total one-off cost of £100,000 the annualised one-off costs are £16,300/year.

Note: This is significantly more than the simple annualised one-off costs of £10,000/year.

6.2 Annual Operating Costs

The annual operating costs are likely to be dominated by energy costs although there are several other cost elements. The various elements are listed below:

- energy supply (electricity, gas, steam, oil, etc.);
- emissions monitoring;
- labour (operating, supervisory and maintenance);
- replacement parts (fans, lamps, burners, etc.).

Suppliers should be able to help you estimate some of these costs.

6.3 Annual Benefits

For any company choosing a new oven, the prime selection criteria will include:

- product throughput; and
- product quality.

The relative abilities of the various oven options in terms of product throughput and/or product quality should be reflected in the cost evaluation. For example, this could be an important issue with infrared systems that can achieve quick curing speeds, hence higher production speeds. For valuing product related benefits, the profit margin per unit output should be used.

A new oven may also result in a lower rate of reject product. For valuing rejects, the lost revenue per unit output should be used.

6.4 Example Cost Evaluation

A company whose business is painting automotive components is looking for a new paint curing tunnel oven. They wish to choose between a gas fired air recirculation unit with or without an infrared pre-heat section. Example costings are given in Table 4 to illustrate the importance of considering all cost elements.

Table 4 Example cost evaluation

Cost element	**Option 1 – Air recirculation unit**	**Option 2 – Air recirculation unit with infrared preheat**
Annualised one-off cost	£16,300/year (£100,000 one-off cost with an annualisation factor of 0.163 i.e. oven lifetime of 10 years and a discount rate of 10%)	£19,560/year (£120,000 one-off cost with an annualisation factor of 0.163 i.e. oven lifetime of 10 years and a discount rate of 10%)
Annual operating costs	£15,000/year (£10,000 gas, £2,000 electricity, £3,000 other)	£12,000/year (£5,000 gas, £4,000 electricity, £3,000 other)
Annual benefits	£2,000/year (compared with existing oven, an additional 1,000 units/year can be cured and sold @ £2/unit profit margin)	£8,000/year (compared with existing oven, an additional 4,000 units/year can be cured and sold @ £2/unit profit margin)
Total annualised cost	£29,300/year	£23,560/year Therefore this is the most cost effective option despite having a higher one-off cost.

7. CONCLUSIONS

The energy used for paint curing or stoving ovens is estimated to cost the engineering industry more than £100 million/year. However, there is often little attention given to the energy consumption of these ovens by the companies that run them.

Most of the energy used in a curing or stoving oven is lost as waste heat. Typically only 5-10% of the total energy used actually heats and cures the coated components in a gas-fired direct air recirculation oven.

It is estimated that about 90% of all the ovens used in the engineering industry are of the direct air recirculation type. They are popular because they relatively inexpensive to purchase and are robust, reliable and flexible in operation. The main alternative oven types are:

- electric infrared;
- gas radiant;
- gas catalytic;
- combination.

These ovens can reduce energy consumption by more than 50% in comparison to direct air recirculation ovens. The energy savings will often more than outweigh the higher capital cost over the lifetime of the oven. So, the next time you are considering buying a new curing or stoving oven, take some time to consider your options.

✗ DO NOT just purchase the ‘same again’;

✓ DO think about your needs carefully (Section 3);

✓ DO use this Guide to identify the type of oven that best meets your needs (Section 3);

✓ DO discuss your detailed requirements with oven suppliers;

✓ DO specify energy efficiency features for your oven (Section 4);

✓ DO ensure that energy efficiency is considered during installation, operation and maintenance (Section 5);

✓ DO check the lifetime costs - an oven that is more expensive to buy initially might be cheaper in the long run (Section 6).

8. APPENDIX A - HOW TO CALCULATE THE ENERGY BALANCE FOR YOUR OVEN

8.1 Data Requirements

It will help you with the energy balance calculations if you check what data you need before you start. You should consider:

- What data do I need?
- Where can I get it from?
- Is it in the correct units?

The data you will need is described below.

Oven wall surface area (m^2) - This total wall surface area can be calculated from the oven length, height and width for simple shaped ovens, but must also include any bulges, eg for the burner box. These dimensions can be obtained from the manufacturer's literature, drawings or (for existing ovens) site measurements.

Oven wall loss factor ($kW/m^2°C$) - See Appendix C

Temperature difference (°C) - This is the difference in temperature between operating temperature and ambient oven temperature. Ambient oven temperature may be current factory temperature, or for box ovens on start up, it may be a higher temperature.

Operating time (s) - For a box oven the operating time will be the length of the heating up and curing period, multiplied by the number of batches in a typical day. For a tunnel oven, it will be the length of oven operation in a typical day.

Exhaust flow rate (m^3/s) - The design flow rate should be available from the oven manufacturer. For existing ovens, actual performance data may be available from commissioning, service or emission monitoring records.

Air density (kg/m^3) - See Appendix D for air density at a range of temperatures.

Specific heat capacity (kJ/kg°C) - See Appendix D for specific heat capacities of common substrate and oven construction materials.

Conveyor weight (kg/m) - This should be available from the manufacturers of tunnel ovens.

Conveyor speed (m/s) - This should be available from manufacturer's data or for existing ovens, from operational knowledge.

Rack weight (kg) - This should be available from the rack supplier. For existing ovens it may be possible to weigh it.

Product load (kg/m) - This is the product feedrate for tunnel ovens and should be available from production data.

Product load (kg) - This is the weight of product/components cured in one batch in a box oven.

8.2 Energy Balance Calculations

You can calculate the individual heat inputs and losses using the equations presented below.

(a) Heat Loss From Oven Wall

You can calculate the heat loss from an oven wall if you know the surface area of the oven, the oven wall loss factor and the temperature difference (between ambient and operating temperature) of the oven.

Equation 1

Heat loss from oven wall *= Oven surface area x Oven wall loss factor*
(kWh) (m²) (kW/m²°C)

$$\textbf{Heat loss from oven wall}\ (kWh) = \text{Oven surface area}\ (m^2) \times \text{Oven wall loss factor}\ (kW/m^2{}^\circ C)$$

$$\times\ \text{Temperature difference}\ (^\circ C) \times \text{Operating time}\ (s)/3{,}600$$

Under start-up conditions it is reasonable to estimate the average temperature difference to be half the value when at steady state conditions.

(b) Heat Loss from Exhaust

To calculate the heat losses from the exhaust (under steady state conditions), you need to know the volume flow rate of the exhaust gases, the initial air temperature and the exhaust temperature.

Equation 2

$$\textbf{Heat loss from exhaust}\ (kWh) = \text{Volume flow rate of exhaust gas}\ (m^3/s) \times \text{Gas density}\ (kg/m^3)$$

$$\times\ \text{Specific heat capacity}\ (kJ/kg\ ^\circ C) \times \text{Temperature difference}\ (^\circ C) \times \text{Operating time}\ (s)/3{,}600$$

Under start-up conditions the temperature difference can be assumed to be half the value when at steady state conditions.

(c) Heat Input To Raise Conveyor/Rack Temperature

You can calculate the heat input for tunnel ovens (under steady state conditions) if you know the conveyor speed and also the weight of the conveyor. It is assumed that the conveyor enters the oven at ambient temperature.

Equation 3

$$\textbf{Heat required to raise conveyor temperature}\ (kWh) = \text{Conveyor weight}\ (kg/m) \times \text{Conveyor speed}\ (m/s)$$

$$\times\ \text{Specific heat capacity}\ (kJ/kg\ ^\circ C) \times \text{Temperature difference}\ (^\circ C) \times \text{Operating time}\ (s)/3{,}600$$

A similar but different equation will apply to calculations involving box ovens.

Equation 4

__Heat required to raise rack temperature__ = Rack weight x Specific heat capacity
(kWh) (kg) (kJ/kg °C)

x Temperature difference x 1/3,600
(°C) (s)

(d) **Heat Input to Raise Product Temperature**

You can calculate the heat input if you know the feed rate for tunnel ovens and the weight of the components for box ovens.

For Tunnel Ovens: Equation 5

__Heat required to raise product temperature__ = Product load x Conveyor speed
(kWh) (kg/m) (m/s)

x Specific heat capacity x Temperature difference x Operating time/3,600
(kJ/kg °C) (°C) (s)

A similar but different equation will apply to calculations involving box ovens.

For Box Ovens: Equation 6

__Heat required to raise product temperature__ = Product load x Specific heat capacity
(kWh) (kg) (kJ/kg °C)

x Temperature difference x 1/3,600
(°C) (s)

(e) **Heat Loss from Open Ends**

The heat loss from the open ends of tunnel ovens cannot easily be calculated. However, it is generally estimated by oven manufacturers to be between 10-20% of the total heat input.

9. APPENDIX B - EXAMPLE CALCULATIONS OF ENERGY BALANCE

Example 1 - Calculation of an Energy Balance of a Gas Fired Air Recirculation Box Oven

A box oven with the dimensions 1.2 m high x 1.0 m wide x 1.5 m long is used to cure the paint sprayed onto a steel component weighing 100 kg. The component is placed on a steel tray which weighs 20 kg and placed in the oven for a 40 minute curing period. The initial warm up period of the oven is 5 minutes. The oven is insulated with 100 mm of mineral wool insulation (density 60 kg/m^3). The operating temperature of the oven is 180°C, the ambient temperature is 20°C. Air is exhausted from the oven at rate of 50 m^3/hr .

1.1 Start-up Period

Data required:

Assume average temperature difference = $\frac{180 - 20}{2}$ = 80°C

Period of operation = 5 minutes

Specific heat capacity of steel = 0.50 kJ/kg °C (see Appendix D)
Approx. specific heat capacity of air at 80°C = 1.008 kJ/kg °C (see Appendix D)
Approx. density of air at 80°C = 1.01 kg/m^3 (see Appendix D)

(a) **Heat Loss from the Oven Wall (Equation 1)**

For panel loss factor (see Appendix C)

Assume mean temperature of insulation = $\frac{\text{(hot face + cold face)}}{2}$ = $\frac{80 + 20}{2}$ = 50°C

Thus, from Table 1 (Appendix C) thermal conductivity = 0.039 W/m °C

and, from Table 2 (Appendix C) panel loss factor = 0.37 W/m^2 °C

Oven surface area = (1.5 x 1.0) x 2 + (1.0 x 1.2) x 2 + (1.5 x 1.2) x 2 = 9.0 m^2

Temperature difference = 80°C

Operating time = 5 x 60 = 300 seconds

Thus, heat loss from oven wall *= 9 x $\frac{0.37}{1,000}$ x 80 x $\frac{300}{3,600}$ =* ***0.02 kWh***

(b) **Heat Loss from Exhaust (Equation 2)**

Volume flow rate = 0.0139 m^3/s

Thus, heat loss from exhaust *= 0.0139 x 1.01 x 1.008 x 80 x $\frac{300}{3,600}$ =* ***0.09 kWh***

Assume the rack and product temperature reach the operating temperature during the start-up period.

(c) **Heat Input to Raise Rack Temperature (Equation 4)**

Heat required to raise rack temperature *= 20 x 0.50 x 160 x* $\frac{1}{3{,}600}$ = ***0.44 kWh***

(d) **Heat Required to Raise Product Temperature (Equation 6)**

Heat required to raise product temperature *= 100 x 0.50 x 160 x* $\frac{1}{3{,}600}$ = ***2.22 kWh***

(e) **Total Energy Input During Start-up**

Total energy input *= 0.02 + 0.09 + 0.44 + 2.22 =* ***2.77 kWh***

1.2 Curing (Steady-state) Period

Data required:

Period of operation = 40 minutes

Specific heat capacity of steel = 0.50 kJ/kg °C (see Appendix D)
Approx. specific heat capacity of air at 180°C = 1.021 kJ/kg °C (see Appendix D)
Approx. density of air at 180°C = 0.78 kg/m^3 (see Appendix D)

(a) **Heat Loss from the Oven Wall (Equation 1)**

For panel loss factor (see Appendix C)

Assume mean temperature of insulation = $\frac{(\text{hot face} + \text{cold face})}{2} = \frac{180 + 20}{2} = 100°C$

Thus, from Table 1 (Appendix C) thermal conductivity = 0.047 W/m °C

and, from Table 2 (Appendix C) panel loss factor = 0.44 W/m^2 *°C*

Oven surface area = (1.5 x 1.0) x 2 + (1.0 x 1.2) x 2 + (1.5 x1.2) x 2 = 9.0 m^2

Temperature rise = 160°C

Operating time = 40 x 60 = 2,400 seconds

Thus, heat loss from oven wall *= 9 x* $\frac{0.44}{1{,}000}$ *x 160 x* $\frac{2{,}400}{3{,}600}$ = ***0.42 kWh***

(b) **Heat Loss from Exhaust (Equation 2)**

Heat loss from exhaust *= 0.0139 x 0.78 x 1.021 x 160 x* $\frac{2{,}400}{3{,}600}$ = ***1.18 kWh***

(c) **Total Energy Input During Steady-state Operation**

Total energy input *= 0.42 + 1.18 = 1.60 kWh*

Total Energy Input

Total energy input = Input during start-up + Input during curing = *2.77 + 1.60 = 4.37 kWh*

Table A.1 Summary of heat input

	Start-up	**Curing**	**Total kWh**	**%**
Wall losses	0.02	0.42	0.44	10.1
Exhaust losses	0.09	1.18	1.27	29.1
Rack heating	0.44	0	0.44	10.1
Product	2.22	0	2.22	50.7
Total	2.77	1.60	4.37	100.0

Example 2 - Calculation of an Energy Balance of a Gas Fired Air Recirculation Tunnel Oven

A tunnel oven with the dimensions 3 m high x 6m wide x 15 m long is used to cure the paint on a steel components being fed into the oven at rate of 3 m/min. The conveyor consisting of a chain and the trolley which weighs 7 kg/m. The product weighs 15 kg/m. The oven is insulated with 100 mm of mineral wool insulation (density 140 kg/m^3). The operating temperature of the oven is 160°C and the ambient temperature is 20°C. Air is exhausted from the oven at rate of 3,000 m^3/hr .

The start-up period for a tunnel oven is typically 30-45 minutes after which it will run for many hours. The energy requirements for the start-up period are therefore considered to be negligible compared to the steady state period of operation.

Steady-state Period

Data required:

Period of operation = 8 hours

Specific heat capacity of steel = 0.50 kJ/kg °C (see Appendix D)
Approx. specific heat capacity of air at 160°C = 1.021 kJ/kg °C (see Appendix D)
Approx. density of air at 160°C = 0.78 kg/m^3 (see Appendix D)

(a) **Heat Loss from the Oven Wall (Equation 1)**

For panel loss factor (see Appendix C)

Assume mean temperature of insulation $= \dfrac{(\text{hot face} + \text{cold face})}{2} = \dfrac{160 + 20}{2} = 90°C$

Thus, from Table 1(Appendix C) thermal conductivity = 0.042 W/m °C

and, from Table 2 (Appendix C) panel loss factor = 0.40 W/m^2 *°C*

Oven surface area = (6 x 3) x 2 + (15 x 3) x 2 + (15 x 6) x 2 = 306 m^2

Temperature rise = 140°C

Operating time = 8 x 3,600 = 28,800 seconds

Thus, heat loss from oven wall** = 306 x* $\frac{0.40}{1000}$ *x 140 x* $\frac{28,800}{3,600}$ *=* ***137 kWh

(b) **Heat Loss from Exhaust (Equation 2)**

Volume flow rate = 0.83 m^3*/s*

Thus, heat loss from exhaust** = 0.83 x 0.78 x 1.021 x 140 x* $\frac{28,800}{3,600}$ *=* ***740 kWh

(c) **Heat Input to Raise Conveyor Temperature (Equation 3)**

Conveyor speed = 0.05 m/s

Thus, heat input to raise conveyor temperature** = 0.05 x 7 x 0.50 x 140 x* $\frac{28,800}{3,600}$ *=* ***196 kWh

(d) **Heat Required to Raise Product Temperature (Equation 5)**

Heat input to raise product temperature** = 0.05 x 15 x 0.50 x 140 x* $\frac{28,800}{3,600}$ *=* ***420 kWh

(e) **Heat Loss from Open Ends:**

Assume 15% of the total heat input is lost through the oven walls

Other Heat inputs = 137 + 740 + 196 + 420 = 1,493

Heat loss from open ends** =* $\frac{1,493}{0.85}$ *– 1,493 =* ***263 kWh

(f) **Total Energy Input:**

Total energy input** =137 + 740 + 196 + 420 + 263 =* ***1,756 kWh

Table A.2 Summary of heat losses

	kWh	**%**
Wall losses	137	7.8
Exhaust losses	740	42.1
Conveyor heating	196	11.2
Product heating	420	23.9
Open ends losses	263	15.0
Total	1,756	100.0

Example 3 - Calculation of the Fuel Running Costs Electric and Gas Ovens)

If an oven system has an installed electricity or gas meter, you can calculate the operating costs of the oven. The calculation procedure is as follows:

Electricity

Unit cost of fuel = 6.5 pence per unit (kWh) (more accurate data is available from your fuel bills)

Meter reading = 100800 units

Period of consumption = 3 months (12 weeks)

Annual hours of operation = 48 weeks per year, 7 days per week, 12 hours per day

Evaluation period = 1 year

No of hours during period of consumption = 12 x 7 x 12 = 1,008 hours

No of hours for annual operation = 48 x 7 x 12 = 4,032 hours

$$\text{Annual operating costs} = 6.5 \times 100{,}800 \times \frac{4{,}032}{1{,}008} = 2{,}620{,}800 \text{ pence} = £26{,}208$$

Gas

The combustion efficiency of the gas oven is assumed to be 85%.

Unit cost of fuel = 1.4 pence per unit (kWh)

Meter reading = 10541 m^3

Period of consumption = 3 months (12 weeks)

Annual hours of operation = 48 weeks per year, 7 days per week, 12 hours per day

Evaluation period = 1 year

Calorific value = 40.5 MJ/m^3

No. of hours during period of consumption = 12 x 7 x 12 = 1008 hours

No. of hours for annual operation = 48 x 7 x 12 = 4,032 hours

Energy consumed

$$= 40.5 \times 10{,}541 = 426{,}910.5 \text{ MJ} = 426{,}910{,}500 \text{ kJ} = \frac{426{,}910{,}500}{3600} = 118586.25 \text{ kWh}$$

$$\text{Annual operating costs} = \frac{1.4 \times 118{,}586.25 \times 4{,}032}{1008} = 664{,}083 \text{ pence} = £6{,}640$$

The meter readings carried out and the operating costs can be compared to the energy balance carried out in Examples 1 and 2.

Oven manufacturers carry out energy balances in order to specify the installed power that is required. They will usually apply a contingency factor of about 30% above the calculated power. This ensures that the extra power is available for unforeseen heat losses.

10. APPENDIX C - OVEN WALL LOSS FACTORS

Calculation procedure of heat losses from oven wall

To obtain the wall loss factor, firstly estimate the mean temperature of the insulation.

$$\textit{Mean temperature of insulation} = \frac{(\textit{hot face} + \textit{cold face})}{2}$$

Then identify the thermal conductivity for the relevant grade of mineral wool from Table A.3:

Table A.3 Thermal conductivity values (W/m °C) of mineral wool insulation

Mean temperature (°C)	**Insulation density (kg/m^3)**			
	60	**80**	**100**	**140**
40	0.037	0.036	0.036	0.036
50	0.039	0.038	0.037	0.037
60	0.040	0.039	0.039	0.038
70	0.042	0.041	0.040	0.040
80	0.044	0.042	0.041	0.041
90	0.045	0.044	0.043	0.042
100	0.047	0.045	0.044	0.044
110	0.049	0.047	0.046	0.045
120	0.051	0.049	0.048	0.047
130	0.053	0.051	0.049	0.048
140	0.056	0.053	0.051	0.050
150	0.058	0.055	0.054	0.051
160	0.060	0.057	0.055	0.053
170	0.062	0.059	0.057	0.055
180	0.065	0.061	0.059	0.056
190	0.067	0.064	0.061	0.058
200	0.070	0.066	0.064	0.060

Then from Table A.4 select the oven wall loss factor (heat transfer coefficient) based on the insulation thickness.

Table A.4 Oven wall loss factor (W/m^2 °C) for different mineral wool thickness

Thermal conductivity (W/m °C)	**Insulation thickness (mm)**					
	75	**100**	**150**	**200**	**300**	**400**
0.036	0.45	0.34	0.23	0.18	0.12	0.09
0.037	0.46	0.35	0.24	0.18	0.12	0.09
0.038	0.48	0.36	0.25	0.19	0.12	0.09
0.039	0.49	0.37	0.25	0.19	0.13	0.10
0.040	0.50	0.38	0.26	0.20	0.13	0.10
0.041	0.51	0.39	0.26	0.2	0.13	0.10
0.042	0.52	0.40	0.26	0.20	0.13	0.10
0.043	0.53	0.41	0.28	0.21	0.14	0.11
0.044	0.55	0.42	0.28	0.21	0.14	0.11
0.045	0.56	0.43	0.29	0.22	0.15	0.11
0.046	0.57	0.43	0.30	0.22	0.15	0.11
0.047	0.58	0.44	0.30	0.23	0.15	0.12
0.048	0.59	0.45	0.31	0.23	0.16	0.12
0.049	0.60	0.46	0.31	.024	0.16	0.12
0.050	0.62	0.47	0.32	0.24	0.16	0.12
0.051	0.63	0.48	0.33	0.25	0.17	0.13
0.053	0.65	0.50	0.34	0.26	0.17	0.13
0.054	0.66	0.51	0.34	0.26	0.18	0.13
0.055	0.67	0.51	0.35	0.27	0.18	0.14
0.056	0.68	0.52	0.36	0.27	0.18	0.14
0.057	0.69	0.53	0.36	0.28	0.19	0.14
0.058	0.71	0.54	0.37	0.28	0.19	0.14
0.059	0.72	0.55	0.37	0.28	0.19	0.14
0.060	0.73	0.56	0.38	0.29	0.20	0.15
0.061	0.74	0.57	0.39	0.29	0.20	0.15
0.062	0.75	0.58	0.39	0.30	0.20	0.15
0.064	0.77	0.59	0.41	0.31	0.21	0.16
0.065	0.78	0.60	0.41	0.31	0.21	0.16
0.066	0.79	0.61	0.42	0.32	0.21	0.16
0.067	0.80	0.62	0.42	0.32	0.22	0.16
0.070	0.84	0.64	0.44	0.34	0.23	0.17

The calculation of the oven wall heat loss is based on the following assumptions.

- The mean temperature of the insulation is an estimation of the average temperature across the insulation.
- The material of construction of the outer oven wall is of medium surface emissivity. This is applicable to materials such as galvanised steel, aluminium paint, alu-zinc and other comparable surfaces which are typical of the types used for ovens.
- The external surface temperature of the oven is below 50°C.
- For the type and temperature of the outer wall material of construction discussed above, the surface coefficient is taken to be 8.0 W/m^2 K.
- The data presented is applicable only to flat surfaces and not cylindrical surfaces.

11. APPENDIX D - PROCESS DATA

Table A.5 The specific heat capacities of different materials of construction

Material	Specific heat capacity (kJ/kg °C)
Aluminium	0.90
Brass	0.38
Copper	0.39
Iron (cast)	0.50
Nickel	0.44
Steel (mild)	0.50
Steel (stainless)	0.50
Tin (solid)	0.21
Titanium	0.52
Zinc	0.39

Table A.6 The specific heat capacities and densities of air

Temperature (°C)	Specific heat capacity (kJ/kg °C)	Density (kg/m^3)
25	1.005	1.18
50	1.006	1.09
80	1.008	1.01
100	1.011	0.94
130	1.014	0.88
180	1.021	0.78
230	1.030	0.71
280	1.040	0.64
330	1.051	0.59

The Government's Energy Efficiency Best Practice Programme provides impartial, authoritative information on energy efficiency techniques and technologies in industry, transport and buildings. This information is disseminated through publications, videos and software, together with seminars, workshops and other events. Publications within the Best Practice Programme are shown opposite.

Further information

For buildings-related publications please contact:
Enquiries Bureau
BRECSU
Building Research Establishment
Garston, Watford, WD2 7JR
Tel 01923 664258
Fax 01923 664787
E-mail brecsuenq@bre.co.uk

For industrial and transport publications please contact:
Energy Efficiency Enquiries Bureau
ETSU
Harwell, Didcot, Oxfordshire,
OX11 0RA
Fax 01235 433066
Helpline Tel 0800 585794
Helpline E-mail etbppenvhelp@aeat.co.uk

Energy Consumption Guides: compare energy use in specific processes, operations, plant and building types.

Good Practice: promotes proven energy efficient techniques through Guides and Case Studies.

New Practice: monitors first commercial applications of new energy efficiency measures.

Future Practice: reports on joint R & D ventures into new energy efficiency measures.

General Information: describes concepts and approaches yet to be fully established as good practice.

Fuel Efficiency Booklets: give detailed information on specific technologies and techniques.

Energy Efficiency in Buildings: helps new energy managers understand the use and costs of heating, lighting etc.