Causes, Consequences and Prevention of Fires in Domestic Refrigeration Systems

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Abstract

This study was proposed to investigate and examine the causes, consequences and prevention of fires occurring in domestic refrigeration appliances. The aims were to analyse such incidents, examine their characteristics and understand the underlying ignition and fire spread mechanisms that have led to their occurrence and how they might be prevented.

The reasons for the cause and spread of domestic refrigeration fires have been examined, using information obtained from the analysis of fire data sets available in Great Britain and on the basis of fire investigations carried out in London. Visits to refrigerator disposal sites and local authority amenity centres also provided information on changes to appliance construction techniques and component use over several decades.

Analysis of the available data suggests that once ignition occurs, fires caused by fridge/freezers are more likely to exhibit a higher degree of fire spread and produce greater levels of damage than other types of white goods appliance (washing machine, dishwasher or tumble dryer). Nearly 80% of fires with fridge/freezers as the source of ignition, spread beyond the first item involved, whilst almost 40% spread beyond the room of origin. Fires involving fridge/freezers also displayed a far higher casualty rate per fire than was found for the other types of appliance.

Based upon evidence obtained from fire investigations a number of common failure modes leading to ignition in domestic refrigeration fires have been identified: (i) starter relay failures; (ii) PTC switch failures; (iii) mechanical defrost switch failures; (iv) capacitor failures; (v) solenoid valve failures; (vi) cut-out switch failures in integrated appliances, and (vii) rodents. Specific fire escalation and spread mechanisms have also been identified: plastic drip trays, “twin-wall” backing materials and polyurethane foam insulation panels.

There is also evidence to suggest that the severity of refrigeration fires in Great Britain is significantly higher than in the USA. Based upon information obtained from LFB fridge and freezer fire investigations, and a comparison between the design and construction of refrigeration appliances used in Great Britain and USA, a number of recommendations have been made which could be used to significantly reduce the risk of a serious fire e.g. avoiding the usage of plastics in appliance housings and in particular employing a metal/non-combustible covering at the back of fridge and freezer appliances and ensuring that insulating foam is separated from the spread of fire by fire resisting material.

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STANDARDS

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UL 250. (1993) UL *Standard for Safety for Household Refrigerators and Freezers.* Underwriters Laboratories Inc. (UL) ISBN 1-55989-461-X

UL 746C. (1995) *Polymeric Materials Use in Electrical Equipment Evaluations*. Underwriters Laboratories Inc. ISBN 1-55989-949-2

BS EN 60335-1:2012+A13 (2017) *Household and similar electrical appliances— Safety — Part 1:* General requirements. BSI Standards LTD. ISBN 978 0580 98622 2

UL 60335-2-24 (2010) *Standard for Household and Similar Electrical Appliances, Part 2: Particular Requirements for Refrigerating Appliances, Ice-Cream Appliances and Ice-Makers* ISBN 0-7629-1178-6

BS EN 60335-1: (2012) *Household and similar electrical appliances— Safety — Part 1:* General requirements. BSI Standards LTD. ISBN 978 0 580 65131

1BS EN 60695-11-5: (2017) *Fire hazard testing Part 11-5: Test flames - Needle-flame test method – Apparatus.* BSI Standards LTD. *ISBN 978 0 580 83795 1*

BS EN 60695-11-10: (2013) Part 11-10*: Test flames — 50 W horizontal and vertical flame test methods Fire hazard testing.* BSI Standards LTD. ISBN 978 0 580 88551 8

BS EN 60695-11-20: (2015) Fire hazard testing Part 11-20: Test flames — 500 W flame test methods. BSI Standards LTD. *ISBN 978 0 580 93575 6*

BS EN 60695-2-10:(2013) *Fire hazard testing – Part 2-10: Glowing/hot-wire based test methods – Glow-wire apparatus and common test procedure*. BSI Standards LTD. ISBN 978 0 580 68472 2

BS EN 60695-2-11: (2014) Fire hazard testing Part 2-11: Glowing/hot-wire based test methods — Glow-wire flammability test method for end-products (GWEPT) BSI Standards LTD. ISBN 9700 580 54940 3

BS EN 60695-2-12: (2010+A1:2014). Fire hazard testing — Part 2-12: Glowing/hot-wire based test methods — Glow-wire flammability index (GWFI) test method for materials. BSI Standards LTD. *ISBN 978 0 580 81086 2*

BS EN 60695-2-13:2010+A1: (2014) Fire hazard testing — Part 2-13: Glowing/hot-wire based test methods — Glow-wire ignition temperature (GWIT) test method for materials. BSI Standards LTD. ISBN 978 0 580 81087 9

CHAPTER 1

Introduction

1.1 Why are domestic refrigeration appliance fires a concern?

Over the past decade, around 500 fires in the United Kingdom have occurred each year, where the cause was found to be a fridge or freezer (Home Office 2019). A number of these incidents have resulted in injuries/fatalities and produced significant levels of property damage. For example, in September 2011, 6 people died and 2 were injured in a serious fire caused by a freezer that badly damaged the ground and first floor of a two-storey semi-detached house in Neasden, London, (LFB Fire Investigation incident no 155184111/2011). A fridge-freezer is also suspected to be the initial cause of the fire that occurred in Grenfell Tower high-rise residential tower block in London, in June 2017 (Glover 2018), which resulted in the death of 72 people.

Moreover, in recent years, whilst the overall number of fires in residential dwellings in London has been falling (e.g. down by 13% over the 5 years from 2011 to 2015), fires started by fridges and freezers, along with other types of faulty “white goods” appliances (i.e. washing machines, tumble dryers and dishwashers) represent a persistent source of fires in the home, that has not followed this downward trend (LFB 2016).

It is therefore extremely important to analyse such incidents to examine their characteristics and understand the underlying ignition and fire spread mechanisms that have led these fires to occur and how they might be mitigated. However, despite the near universal use of domestic refrigerators in the home, relatively few studies have been made of the characteristics, causes and consequences of fires involving such systems in residential dwellings. There is therefore a need for a research study to examine the causes, consequences and prevention of refrigeration fires in residential dwellings.

1.2 Fire Data

The thesis refers to England, Great Britain, and UK in various tables and data sections and Chapters. Information from fires in the UK have been largely available in various forms from 1950 until 2008. The tables of data were often changed, sometimes to incorporate different terminology or to add new appliances, equipment or to record changing data sets. In 2009 the home office changed the recording system to allow for computer data to be imputed by individual brigades and fire authorities. Northern Ireland opted to record their data in a different way and this data is not available from the home office. It is also difficult to obtain. This has resulted in data sets being available from Great Britain (with England, Scotland and Wales breakdowns). The Home Office have now decided that:

> Previous to ‘Fire statistics: England April 2014 to March 2015’ these publications covered Great Britain, however, after a survey of Fire Statistics Great Britain users, it was decided to change the scope of the release to reflect user needs.
> This collection covers annual bulletins presenting detailed statistics on fires, attended by fire and rescue services across England and casualties in these fires. (Home Office 2012)

Northern Ireland products and appliances and their regulations/guidance are covered by UK regulations and practices. Early data is therefore UK listed and later data is Great Britain listed. As a single European market member, our current alignment to Europe requires harmonisation of Standards and guides where possible.

1.3 Background

From 2003, FIT investigators of the LFB became increasingly aware of a series of fires involving domestic refrigeration appliances (fridges, freezers and fridge-freezers). These fires often seemed to result in casualties and hospitalisation. There was also a strong suspicion that these fires were becoming more severe in nature than had previously been the case, involving not only the whole of the appliance, but often spreading beyond it, leading to greater levels of fire and smoke damage and casualties resulting.

The initial LFB investigations centred on fires involving compressor starter switch's (predominantly in built-in units). Although the appliances involved were made by several different manufacturers, it soon became apparent that the appliances shared a common failure mode, involving a starter switch component. Following the positive identification of the cause of these fires and the eventual successful recall of the compressor starter switch's involved, it was therefore a natural progression to continue the research and investigate the wider causes and consequences of such refrigeration appliance fires, which are the subject of this thesis.

1.4 Investigating fires

As with many disciplines, knowledge and experience is often gained as a result of a repetitious process. Whilst an investigator works with an open mind, investigations will often follow the same process. Having established an initial area of origin, be it a property, a floor, a room, or simply an item within a room, an investigator will observe, record, listen and process information. Since every fire has the potential to be a criminal act, it is important that a protocol of investigation is followed (the fire investigation). Since the investigation more than likely will result in the disturbance, movement and possibly the destruction of evidence, the investigator must be convinced that the scene and evidence available is not a potential crime scene. The introduction of a flame to the compressor compartment of a refrigerator will produce the same resulting fire pattern as a capacitor failure of the same product. Whilst the pattern of burning may clearly indicate to the investigator the area of origin, the process in arriving at a conclusion will still require the same thorough analysis and process before reaching a conclusion.

1.5 The evolution of appliance design

Any electrically powered appliance has the potential for failure. Safety should therefore be one of the principle considerations in the design and production of such a product. However, the need for more flexible designs and lower production costs has increasingly led to plastics replacing the metal or wood framing, interior shelving, and even component parts. The drive for greater energy efficiency has also resulted in the use of significant quantities of insulating foam, which now add significantly to the fire loading. The use of flammable gas as the blowing agent for the insulating foam and finally the most common refrigeration gas in current use is Isobutane R600a. Almost every aspect of a modern domestic refrigerator has the ability to significantly add to the both the fire loading and to the potential for a severe fire with a greater risk of injury or death should a failure take place.

1.6 Aim of the research

The aim of this research study has been to examine:

- the causes of fires in domestic refrigeration appliances
- Highlight the consequences of such fires and their potential for injuries and deaths.
- Examine how prevention of domestic refrigeration appliance fires can be achieved.
- Examine the limitations of current data recording from fire incidents.

To achieve this, extensive use has been made of the experience and information obtained via fire investigations carried out by LFB in London.
In working and producing data and information from actual incidents, the difficulties with current restrictions on fire statistics, product information, product identification and marking of appliances together with the limiting sharing of current product information will be shown and discussed. The increase in fire risk particularly in domestic refrigeration appliances is highlighted together with the growing risk of fire development in modern domestic appliances.

1.7 Objectives

To meet this aim, the main objectives of the research study were to:

- Collect and analyse data on domestic refrigeration appliance fires obtained from fire investigations
- Analyse and compare different white goods appliance fires (injuries/fatalities, fire damage levels)
- Identify the failure modes responsible for the ignition of fridge/freezer fires
- Comparison of different fire standards and codes applicable to domestic refrigeration appliances (United Kingdom/European vs United States) UK/EU vs US
- Identify ways in which fridge/freezer fire safety could be improved

1.8 Thesis Overview

Chapter 2 sets out the relevant background to the project and surveys the previous work that has been carried-out, in relation to the development and fire safety of domestic refrigeration appliances. It begins by examining the historical development of the domestic refrigerator from early mass production in the USA of the 1920's to modern day appliances, highlighting the evolution of its design and construction, and describing how a modern domestic refrigerator works. It then considers some under-pinning concepts of fire science (fuel sources, ignition, fire spread) before looking in more detail at the fire safety of domestic refrigeration appliances – reviewing the relevant standards and tests and previous research studies that have been carried-out in the area.

Chapter 3 sets out the fire investigation procedures used by London Fire Brigade and the methodology that has been used for investigating domestic appliance fires considered in this study. Through the recording of details from fires over previous years, LFB fire investigation has provided access to the specific details of many case histories for incidents involving domestic refrigerators. Many of the incidents have resulted in samples being removed and examined by forensic scientists. By employing the methodology described in this chapter, the information collected from the scene of fire investigations involving domestic refrigeration appliance has been used in Chapters 5 and 6 to identify possible ignition and fire spread mechanisms occurring in fridge and freezer fires.

In Chapter 4 is the analysis of the available residential dwelling fire data (for England and London) and has been carried out to identify the characteristic statistical features of fires involving refrigeration appliances. In particular, a comparison has been made between the characteristics (i.e. frequency and consequences) of fires caused by faults in fridge/freezers and fires caused by faults in other comparable types of domestic “white goods” appliance (washing machines, dishwashers and tumble dryers).

In Chapter 5, a number of common failure modes that can lead to ignition in domestic refrigeration appliances are identified:

- Overheating starter relays
- Positive temperature coefficient starter (PTC) switch’s
- Mechanical defrost switch timer failures
- Capacitor failures
- Cut-out switch failures in integrated appliances
- solenoid valve failures
- Rodents causing mechanical damage

A discussion of each of these different failure modes is given, along with examples of each type of failure that have been encountered in practice.

In Chapter 6, several mechanisms that have been found to produce fire escalation and flame spread in domestic refrigeration appliances are identified and examined - all of which result from the usage of plastics in modern appliance construction. These mechanisms help to explain why fires involving domestic refrigeration appliances are more likely to exhibit a higher degree of fire spread and produce greater levels of damage and casualties than are found for fires involving other types of white goods appliance.

Chapter 7 discusses why a higher proportion of fires in fridge/freezers spread beyond both the appliance and the room of origin than is the case for the other types of appliance and why they are more likely to result in high levels of fire damage. It also makes comparisons between Great Britain and USA (in terms of both fire casualties and standards/regulations), and suggests measures that could be adopted in the UK to reduce the likelihood and consequences of domestic refrigeration fires.

Finally, in Chapter 8, a number of conclusions based upon the findings of the research are drawn and some areas for future work are suggested.

Chapter 2

Literature Survey

2.1 Introduction to chapter

This Chapter sets out the relevant background to the project and surveys the previous work that has been carried-out, in relation to the development and fire safety of domestic refrigeration appliances.

It begins by examining the historical development of the domestic refrigerator, the evolution of its design and construction, and how a modern domestic refrigerator works. It then considers some under-pinning concepts of fire science (fuel sources, ignition, fire spread) before looking in more detail at the fire safety of domestic refrigeration appliances – reviewing the relevant standards and tests and previous research studies that have been carried-out in the area.

2.2 Historical development

The development of 'modern' domestic refrigeration appliances grew out of the success of commercial refrigeration storage. In early 20th century USA,

refrigeration in domestic settings relied largely on the delivery by ‘the iceman’ in the form of large cut ice blocks placed in cabinets. The US climate, unlike the British weather, made ice and cooling an essential requirement.
Fred W. Wolf Jr is attributed with producing the first commercially viable electric refrigerator - the DOMELRE - in the United States, in 1913 (Figure. 2.1). This appears to have been a conversion, rather than a totally new product, consisting of an icebox with an air-cooled refrigeration attached to the top (Hertzman 2016)

The first self-contained electric refrigeration unit was designed by Alfred Mellowes, in 1915. The design, which featured a compressor positioned at the base of the unit, was initially adopted and sold by the Guardian Refrigerator company in 1916. The company was subsequently acquired and rebranded Frigidaire, with refrigeration appliances being produced in Detroit from 1918.

Figure 2.1 The Domelre - Domestic Electric Refrigerator (Chapman, 2010)

The growth of United States (US) ownership of domestic appliances, started in the 1920’s and was largely successful due to both the installation of electrical power and the mass production techniques of the motorcar industry, who were able to apply similar techniques in the construction of refrigerators. In 1920, a domestic refrigerator in America was likely to cost an average of $600. By 1929 the cost had fallen to $292 and by 1940 was an average of $154. (Rees, 2013)

In 1920, US production was quoted as 10,000 units. By 1929 the increase was to 840,000 appliances a year and by 1940, 2,720,000 (ASRE 1943). By the 1930’s, the designs were changing to become more aesthetic with greater functionality. Increased food storage volume, reduced energy consumption and greater cooling capacity were sought. There was also a greater use of enamelled metals and innovations such as door shelving (patented 1933). By 1936 the ownership had grown to 6.250,000. By the 1940’s compartments for freezing, with individual butter storage and rust proofed shelving were common. Separate freezer models were also produced, but initial sales were reported to be poor.

By the 1950’s it was estimated that 90% of US homes had a refrigeration appliance. By contrast, adoption in the UK and across mainland Europe was slower to develop. In the UK, ownership by 1948 was estimated at just 2% of households. 98% of households had no means of chilling milk or butter, no receptacle from which to pull crisp lettuces and cartons of cold juice, no way of making an ice cube. Stored meat was placed in a wire mesh 'safe' in the larder, vegetables wilted on a rack. Even by 1959, only 13 per cent of homes had a refrigerator.

The refrigeration adoption rates also varied considerably between different countries around the World (Table 2.1). Some of the countries with colder climates were using refrigeration in greater quantities than their warmer neighbours. As late as 1951, the West German government considered taxing refrigerators as luxury goods.

Table 2.1 Adoption rates for refrigerators around the World in 1957.

Country	% of homes with refrigerator
United States	90+
Canada	84
Australia	70
Sweden	50
New Zealand	26
Denmark	25
West Germany	14
France	12
Italy	11
Great Britain	<10

(Rees, 2013)

The proportion of the World's refrigerators constructed in the United States also fell from 90% in 1939, to just 37% by 1958, and by the early 1960's more refrigeration appliances were constructed in Europe than the US.

2.3 Evolution of design and construction

2.3.1 Layout

Mechanical refrigeration design and construction was originally divided between individual refrigeration appliances and ice boxes. Ice boxes were predominately used in apartment blocks. The compressor and working components were normally housed in the basement and gas was piped to the individual apartments feeding a 'cooled ice box' compartment (see Figure 2.2).

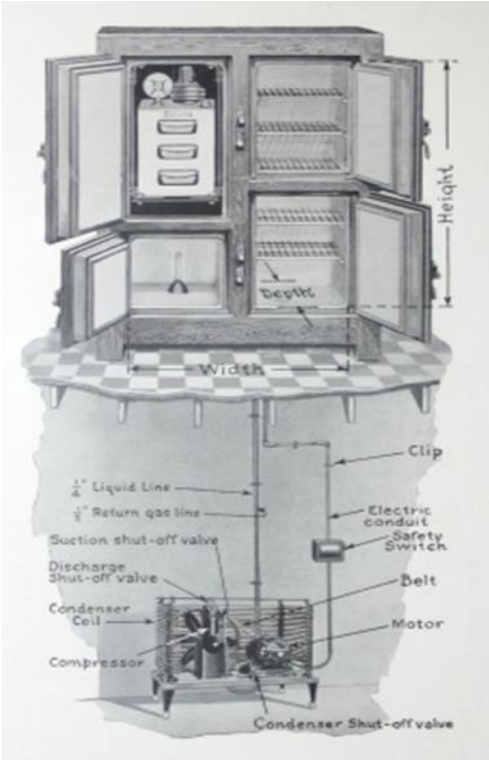


Figure 2.2 An early Kelvinator 1920's refrigerator showing the refrigerator with connecting pipework to the basement. (Kelvinator Corp, 1926)

Mass production of individual appliances slowly replaced these communal 'ice box' systems. The successful designs such as the popular monitor top refrigerator range (Figure. 2.3), with their top mounted compressors sold in large numbers, with the base mounted compressor developed towards the end of the decade. A simple monitor top refrigerator requires at least four persons to lift it.

Figure 2.3 A monitor top refrigerator produced by General Electric in 1927. (Smith C. 2005)

In following years, as refrigerator design further evolved, the compressor was moved from on top of the appliance, to the base at the rear of the cabinet, presumably to improve the aesthetic appeal and reduce the amount of noise exposure.

2.3.2. Refrigerants

A refrigerant is a substance used in the refrigeration cycle to transfer heat from the interior to the exterior, typically undergoing a phase transition between being a liquid and a gas.

In choosing the most suitable refrigeration gas the following points must be considered:

- Thermodynamic properties
- Corrosive actions on components
- Efficiency
- Toxicity level
- Flammability
- Cost and availability

In recent years environmental issues have added some further important considerations to this list

- Ozone depletion level
- Global warming level
- Recycling/disposal potential

The three most common domestic refrigerants in use from the 1920's were:

- Methyl Chloride (Chloromethane – CH_3Cl)
- Sulphur Dioxide (SO_2)
- Ammonia (NH_3)

The main concern with these early refrigerants was that they are all toxic and harmful to human health. (Smith C 2005) Inhalation of methyl chloride at lower levels causes drowsiness, whilst higher concentrations result in paralysis and death. Ammonia inhalation can result in burning to the respiratory tract and is also extremely toxic. Both Ammonia and sulphur dioxide are detectable at low levels. A catastrophic leak can overwhelm room occupants very rapidly.
Ammonia has been successfully used in industrial systems where it can be monitored and maintained but its use in domestic appliances has been limited. Inhalation of sulphur dioxide leads to difficulty in breathing and risk of premature death. Although a poisonous gas, sulphur dioxide has a noxious,

burnt match smell, which meant that most owners could detect and evacuate their homes before being poisoned. It was also not fully appreciated that if water gets into the refrigerator’s closed compression system, it bonds with sulphur dioxide to form sulphuric acid, which can eat through the parts of the machinery it touches.

The interpretation of many of these issues by manufacturers at the time were either ignored or poorly researched. In choosing a suitable gas the dilemma appeared to be that each has serious issues, should it leak or fail when used and that the dangers where justified on the basis of risk. These early systems were expensive and regular maintenance and repair was an accepted principle of ownership.

2.3.3. Deaths and poisoning in Chicago.

In Chicago in July of 1929, a number of poisonings and deaths that were linked to leaking refrigerant (methyl chloride) occurred resulting in a Coroner’s inquest. At that time around a third of the refrigeration appliances in Chicago (numbering about 15,000), produced by the five leading manufacturers, used methyl chloride. At the inquest, the refrigerator manufacturers argued that they had invested a great deal of money in their development, that the gases in use at the time were safe and that methyl chloride was the least toxic of the three: (Chicago Tribune, Daily Illini, The Urbania Daily 1929)

> *There is, of course, some possibility of danger. Ammonia, sulphur dioxide and methyl chloride are the three gases most commonly used. None can be breathed with impunity but none are violent poisons when breathed for short periods in low concentration*. (*Times of New York 1929*)

The medical view however was to express concern over the gas, which they deemed to be poisonous. To confirm this, two guinea pigs were placed within the affected apartment overnight. The Coroner returned the following morning to find both animals had died, confirming the fatal attributes of the gas. The inquest concluded that leaking methyl chloride gas had poisoned the occupants and showed that a number of previous incidents had also taken place. It was also concluded that it was the apartment house refrigeration systems, working from a central unit, that were causing the deaths and that single refrigeration units posed much less of a concern. The coroner recommended discontinuing the use of methyl chloride, unless some sort of odorant was applied. This led to a ban of the use of methyl chloride by the city. (The Sun, Baltimore July 2 1929)

Poisoning by methyl chloride has been so infrequent that textbooks on toxicology and legal medicine, either mention it briefly or fail to record the toxic properties of the gas. (KEGEL 1929)

It seems that these issues were also not confined solely to the USA. In 1926, it is recounted that Albert Einstein was appalled to read of yet further deaths in Berlin. Attributed to yet another leaking refrigerator it was reported that the whole family was wiped out following a toxic gas leakage from a refrigerator seal. The family perished in their sleep. This apparently led him to design and patent a number of safer refrigeration systems. (Dannen 1997)

2.3.4 Refrigerant gasses.

The challenge of finding a safer refrigerant gas was thought to have been overcome, in 1928, when Thomas Midgley Jr., aided by Charles Franklin Kettering, invented a "miracle compound" called Freon. Freon (R12) represents several different chlorofluorocarbons, or CFCs, which are used in commerce and industry **(**Giunta 2006). Because Freon is non-toxic and non-flammable, it eliminated the danger posed by refrigerator leaks. In just a few years, compressor refrigerators using Freon would become the standard for almost-all domestic use. Production of the gas lasted from the 1930’s until its general replacement by R134a also known as Tetrafluoroethene (CF3CH2F) from the family of Hydrofluorocarbons (HFC) refrigerants, in the 1970s.

The discovery that R134a has a high global warming potential (GWP) led to the use of this refrigerant being prohibited in the 1990's. Consequently, a further change in refrigerant gas usage occurred from around 2000, and almost all current domestic appliances in Europe now use the hydrocarbon, isobutane (R600a). This has zero ozone depletion potential (ODP) and a negligible global warming potential GWP. It is however extremely flammable and adopted throughout Europe. The USA have recently adopted R441a, a hydrocarbon mixture, for domestic refrigeration use (2011).

Absorption refrigerators started mass production in the domestic market, around 1925 utilising an ammonia solution. This type of refrigerator has survived in use and are often now found in recreation vehicles today, where alternatives to electricity can power the heater. They were in use in the 1970's in many hotel rooms and also in student accommodation where their almost silent operation made them suitable for use in sleeping areas. Hospitals where also a common user of this design and a large number have had major evacuations as a result of leaks.

Table 2.2 lists of some of the common refrigerant gasses both in use and withdrawn.

Table 2.2 Refrigerant gases and properties in use and withdrawn

Refrigerant	Chemical Name/ Blend Composition	Chemical Type	Safety Class	ODP (MP)	GWP (100)
R11	Trichlorofluoromethane	CFC	A1	1	4750
R12	Dichlorodifluoromethane	CFC	A1	1	10890
R22	Chlorodifluoromethane	HCFC	A1	0.055	1810
R32	Difluoromethane	HFC	A2L	0	12400
R114	1,2-Dichlorotetrafluoroethane	CFC	A1	1	10040
R123	1,1-Dichloro-2,2-2-Trifluoroethane	HCFC	B1	0.02	77
R124	1-Chloro-1,2,2,2-Tetrafluoroethane	HCFC	A1	0.02	527
R134a	1,1,1,2-Tetrafluoroethane	HFC	A1	0	1430
R142b	1-Chloro-1,1-Difluoroethane	HCFC	A2	0.07	2310
R143a	1,1,1-Trifluoroethane	HFC	A2L	0	4800
R152a	1,1-Difluoroethane	HFC	A2	0	124
R170	Ethane	HC	A3	0	5.5
R290	Propane	HC	A3	0	3
R401A	R22/152a/124	HCFC	A1	0.04	1180
R401B	R22/152a/124	HCFC	A1	0.04	1290
R402A	R125/290/22	HCFC	A1	0.03	2420
R403A	R290/22/218	HCFC	A1	0.04	3120
R403B	R290/22/218	HCFC	A1	0.03	4460
R404A	R125/143a/134a	HFC	A1	0	3920
R407C	R32/125/134a	HFC	A1	0	1770
R409A	R22/124/142b	HCFC	A1	0	1590
R409B	R22/124/142b	HCFC	A1	0.05	1560
R410A	R32/125	HFC	A1	0	2090
R413A	R218/134a/600a	HFC	A2	0	2050
R417A	R125/134a/600	HFC	A1	0	2350
R441a	R170/290/600a/600	HC	A3	0	3.6
R500	R12/152a	HCFC	A1	0.74	8070
R502	R22/115	HCFC	A1	0.33	4660
R600a	Isobutane	Natural	A3	0	4
R717	Ammonia	Natural	B2L	0	0
R744	Carbon dioxide	Natural	A1	0	1
R1234yf	2,3,3,3-Tetrafluoropropene	HFO	A2L	0	4
R1270	Propane	Natural	A3	0	2

Summary table of Refrigerants

Prefix	Meaning
CFC	Chlorofluorocarbon
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
HC	Hydrocarbon
HFO	Hydrofluoroolefin

ISO 817 Refrigerant Classification scheme

Lower Toxicity	Higher Toxicity	
A3	B3	Higher Flammability
A2	B2	Flammable
A2L	B2L	Lower Flammability
A1	B1	Non-flammable

Ozone Depletion Potential ODP

ODP is measured relative to CFC 11 (Chlorofluorocarbon-11) and it represents the amount of ozone depletion caused by a substance, on a mass per kilogram basis.

Global Warming Potential GWP

The GWP is the ratio of the warming caused by a substance to the warming caused by a similar mass of carbon dioxide.

The EU F-Gas regulations (517/2014) set strict guidelines on the usage and emission of fluorinated greenhouse gases (F-Gases) used as refrigerants (including HFCs) in the EU. Any domestic refrigeration appliances containing HFCs that reaches the end of its life must be disposed of in accordance with these regulations such that any HFC gas present in the cooling system or insulating foam is recovered. In the UK old refrigeration appliances are usually sent to special waste handing plants, operated by the local authority, where the refrigerant can be recovered. The foam insulation will also be shredded to allow recovery of the blowing agent.

2.3.5 Construction methods - housing

The refrigeration units of the 1920s were commonly constructed with metal linings that sealed the cork and chipboard insulation panels. These quickly progressed to all steel cabinets then to porcelain on steel making the heavy casings almost indestructible. Further evolution of design, to improve performance and reduce costs, led to the introduction of new materials – most notably plastics.

2.3.6 Inner Door and Inner Liners

High impact polystyrene (HIPS), first became available in the mid-1950s. It was light, relatively inexpensive to produce and could be readily heated and moulded into complex shapes (thermoforming). Hence it could be used to form functional inner refrigerator doors panels, incorporating moulded shelves, significantly increasing the available food storage space. Later designs also used acrylonitrile butadiene styrene (ABS) a tough plastic with chemical and stress resistant properties, to create functional inner doors. The successful use of these materials in the inner door paved the way for wider use of plastics throughout the appliance.

Plastics (ABS and HIPS) were also first used in the 1970s to make one-piece cabinet liners, reducing the cost and further improving the insulation between the interior and exterior. The ability to form a smooth single piece liner allowed the merging of a number of previously separate components, simplifying design, cleaning and the cost of manufacture. The process could also be adapted to form thicker walls in the freezer than the refrigerator compartment, further improving insulation.

2.3.7 Refrigeration insulation

In order to help maintain a cool temperature inside the appliance, insulation is required to prevent the transfer of external heat into the interior. The more effective the insulation, the less energy the appliance uses to stay cool. In addition to energy savings, the insulation prevents condensation from forming on the outside of the unit. By keeping the air inside the unit dry, it also prevents ice build-up in the freezer.

The early mass-produced appliances used insulating materials such as cork and felt and even employed chipboard and timber illustrated in Figure 2.4.

Figure 2.4 Cross-section illustrating the insulation materials used for the side-wall and door in a 1920's Kelvinator refrigerator (Kelvinator Corporation, 1926)

With the development of fibreglass, towards the end of the 1930's, many appliance designs switched to using fibreglass insulation. This was used through to the 1970's. However, fibreglass insulation was known to have a number of deficiencies. It could fail, allowing water to leak into the insulation compartment or condense on it and freeze, producing a thermal bridge. Fibreglass insulation provides no internal rigidity or strength and so requires a substantial frame to hold it in place. It is also difficult to maintain fibreglass around pipework and wiring. Hence, alternatives were sought. Foam insulation was originally introduced in the mid 1950's. Frigidaire introducing 'Frigi-Foam' insulation in 1958, the first "Frost-Proof" refrigerator-freezer (UK

Whitegoods, 2007) Expanded polystyrene foam was also first introduced in 1956 to form a one-piece divider.

Further innovations with plastics in the late 1950s and early 1960s led to the introduction of cellular polyurethane expanded foams formed by using a refrigerant gas R-11 (now known as CFC-11) as a blowing agent (see section 2.3.9.). Such gas expanded foams proved to be far more effective insulators than fibreglass.

Polyurethanes became widely used as refrigerator insulation in the mid-1980s. Rigid polyurethane (PU) foam is the insulation material, which is now most widely used throughout the world in refrigerators and freezers. The insulation efficiency of polyurethane foams is a key property for the low temperature preservation of food. Fully integrating rigid foam insulation into refrigerator construction resulted in a more efficient unit. Its insulating properties have allowed for thinner walls, providing greater storage space and enabled much greater energy efficiencies *(*Polyurethanes 2017)

The manufacturing process was adapted to inject liquid polymer and gas blowing agent into the cavity between the outer housing and inner wall of the refrigeration appliance, which expands and then sets to form a cellular insulation foam. The foam sandwich panel created is a highly effective insulator whilst also being relatively strong and rigid, allowing the total amount of material used between the inner and outer walls to be reduced by up to 50%. The rigidity of the insulation also makes it possible to use only a thin-sheet steel housing construction.

2.3.8. The amount of plastic used in construction

Modern day refrigerators and fridge/freezers are the principle users of plastics out of all the domestic appliances. As a result, plastics can make-up around 25% of the total mass of the appliance and over 60% by volume (Hagan, 1994)

2.3.9. Blowing agents

In order to form rigid plastic foams, such as polyurethane a blowing agent is required. Such blowing agents diffuse through the plastic reacting medium forming bubbles, which expand to create a foam.

Carbon dioxide (produced by reacting isocyanate with water) was used as a blowing agent to form PU foam, up until the late 1950's. However, it was the introduction of CFCs as a physical blowing agent, in the late 1950's, that really accelerated the widespread use of PU foam. CFCs make ideal blowing agents, since they are low cost, very stable, have a low molecular weight, low thermal conductivity, low toxicity, a boiling point around room temperature and are non-flammable (Singh, 2002). Using CFC's as a blowing agent, particularly trichlorofluoromethane (CFC-11), produces a low density, closed cell rigid foam, with high mechanical strength and excellent thermal insulation properties (i.e. low thermal conductivity or k-factor) superior to that which could be achieved by other plastic foams. Hence, they became the blowing agent of choice for PU foams, until it was discovered that they were having a detrimental impact on the environment, depleting the ozone layer in the Earth's upper atmosphere.

Alternative blowing agents have therefore been sought. Hydrofluorocarbons (HFC) were used initially, but have a high global warming potential (GWP).
In the case of modern refrigeration appliances, the foam insulation is often blown with hydrocarbon blowing agents – usually cyclopentane (n-pentane and 1-pentane are also used). Hydrocarbons (HC) do not deplete ozone and have a low GWP, but are flammable. To safely use such flammable blowing agents, the risks due to ignition, storage and transportation, and the fire performance of the both foam and the finished product should all therefore be evaluated (Singh, 2002).

2.4 How a modern domestic refrigerator works

2.4.1 Vapour Compression Refrigerator Cycle

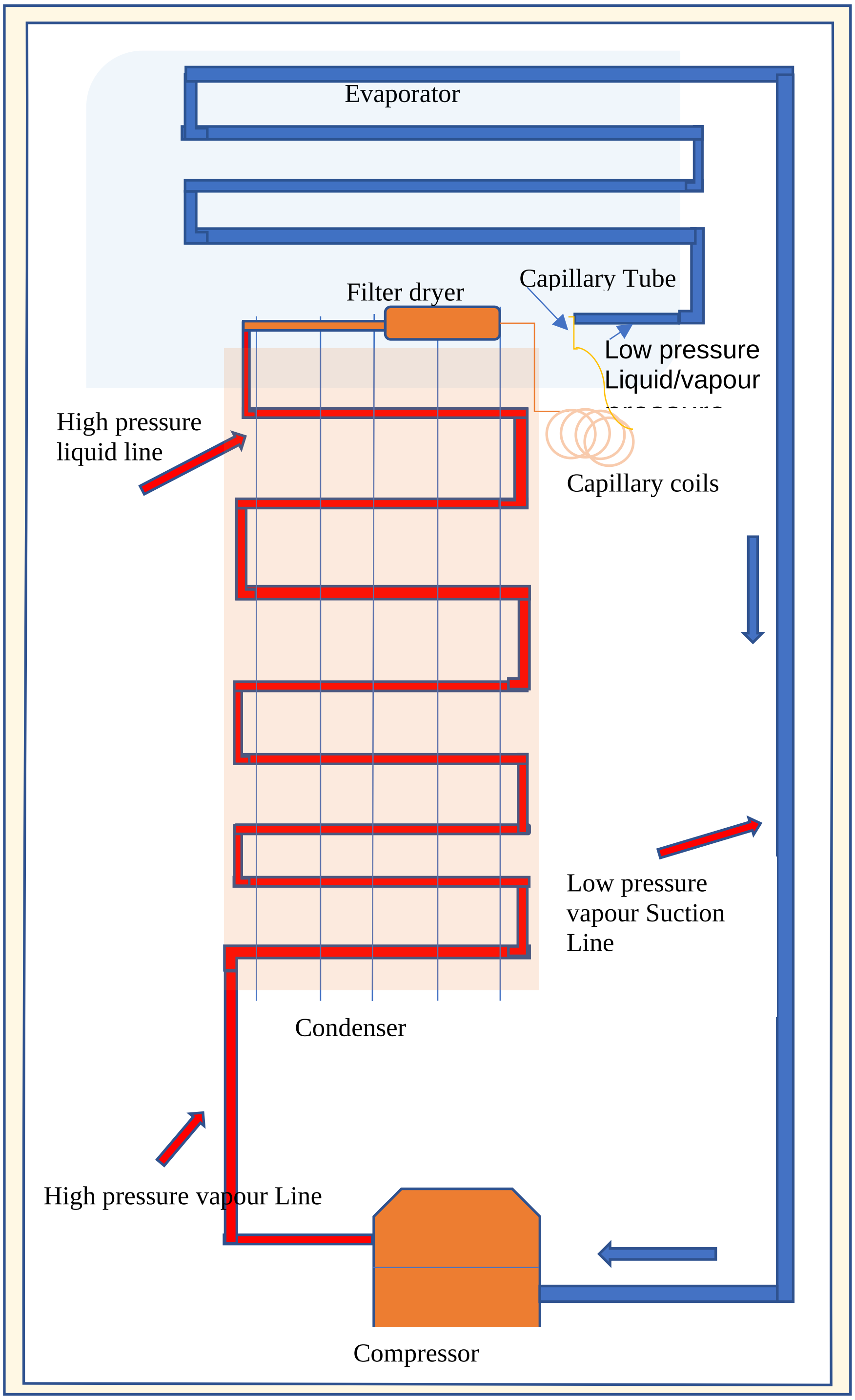


Figure 2-5 Basic Vapour compression cycle refrigeration (VCR) diagram

Vapour-compression refrigeration systems (VCRS), in which the refrigerant undergoes four phase changes, is the most commonly used in domestic refrigeration appliances today. It is also used extensively in air conditioning and motor vehicle refrigeration.

- Phase one: Compression

  When power is supplied to the compressor, Low pressure vapour is drawn into the compressor chamber via a pipe and is compressed by a rapidly moving piston. Heat generated by the compression of the vapour (super-heated) is forced into the condenser tube system under pressure.
- Phase two: Condensation

  Heat generated in the compression sequence is dissipated in the condenser matrix. This cooling allows the refrigerant gas to liquify, the gas passing through the filter/dryer which removes traces of water vapour or crystals before passing through the capillary tube and on to the evaporator
- Phase three: Evaporation.

  The small-bore capillary tube controls the flow of high-pressure liquid and as it enters the large network of the evaporator, this sudden expansion result in rapid cooling of the unit as it reverts to a lower pressure liquid/vapour once more.

  As a sealed system the low-pressure vapour is drawn back to the compressor to allow the cycle to continue.

From around the year 2000, one major UK retailer, imported a large volume of appliances offering both manual or automatic defrost capability. They chose to mount the defrost timer at the back of the appliance. Although the switch was in common use, it was rare to find the unit mounted in this way Figure 2.6 Shows this defrost timer switch and is referred to in detail in section 5.4.

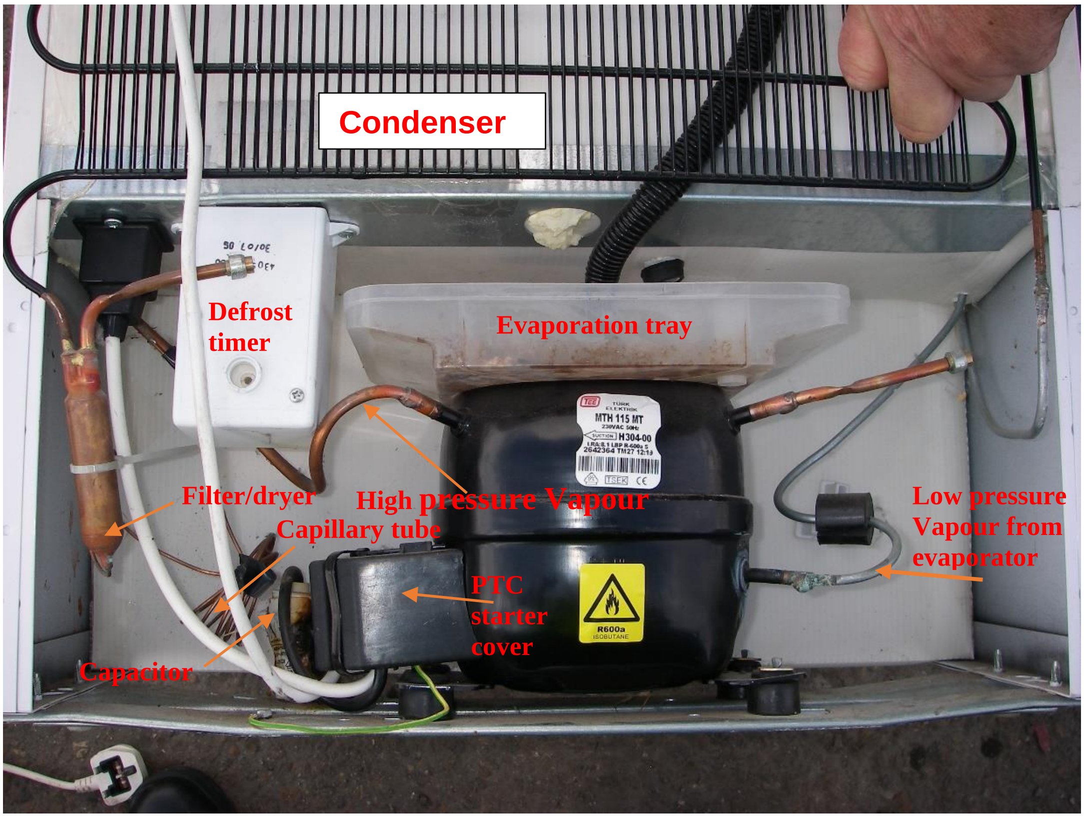


Figure 2.6 Modern VCR Fridge/freezer showing components in compressor area. (Amenity site 08/2009)

Common components found within a VCR refrigeration appliance can be found in Appendix A.

2.4.2 Vapour Absorption Refrigerator

The vapour absorption cycle utilises water-ammonia sealed within a closed circuit. The appliances were popular and widely used but found to be less efficient than the vapour compression cycle. Due to its low coefficient of performance compared to the vapor compression cycle. The heating process required, could be provided from a number of sources including gas, electric or even by open flame. The appliance was also popular in households without electricity. Nowadays, the vapor absorption cycle is used more commonly in recreation vehicles and caravans or where the absence of noise is important.

The absorption cycle is similar to the compression cycle, except for the method of raising the pressure of the refrigerant vapour. In the absorption system, the compressor is replaced by an absorber which dissolves the refrigerant in a suitable liquid, a liquid pump which raises the pressure and a generator which, on heat addition, drives off the refrigerant vapour from the high-pressure liquid. Some work is required by the liquid pump but, for a given quantity of refrigerant, it is much smaller than needed by the compressor in the vapour compression cycle. In an absorption refrigerator, a suitable combination of refrigerant and absorbent is used. The most common combinations are ammonia (refrigerant) and water (absorbent), and water (refrigerant) lithium bromide (absorbent).

Domestic Vapour absorption refrigerators are not commonly available in the domestic refrigeration market in the UK. Whilst the use of ammonia has been well established in commercial use, it is generally limited to the leisure market for camping, caravan etc. There has been a limited supply of small table top appliances often labelled as ‘bottle’ fridges. There are still a number of appliances that were available from the second hand market. These are the most common that the fire service encounter. We generally attend these incidents as either chemical leaks, or as explosions when the metal weld fails close to the boiler, a common fault.

- **Energy efficiency:** With a greater focus on energy consumption, ammonia systems are considered a safe and sustainable choice for the future.
- Environment: With a Global Warming Potential (GWP) and an Ozone Depletion Potential (ODP) equal to zero, it is one of the most environmentally friendly refrigerants, belonging to the ‘natural’ group of refrigerants.
- Safety: Ammonia is an extremely toxic refrigerant, and it is also flammable at certain concentrations. All ammonia systems require a high degree of safety in design, its characteristic odour is quickly detected even at very low concentrations but a catastrophic leak can overwhelm room occupants very rapidly. This is the primary reason

for the choice of Vapour-compression refrigeration systems over ammonia systems in the current market.

Figure 2.7 illustrates a typical circulating, sealed vapour absorption refrigerator. A choice of heat sources can be utilised to provide the energy input.

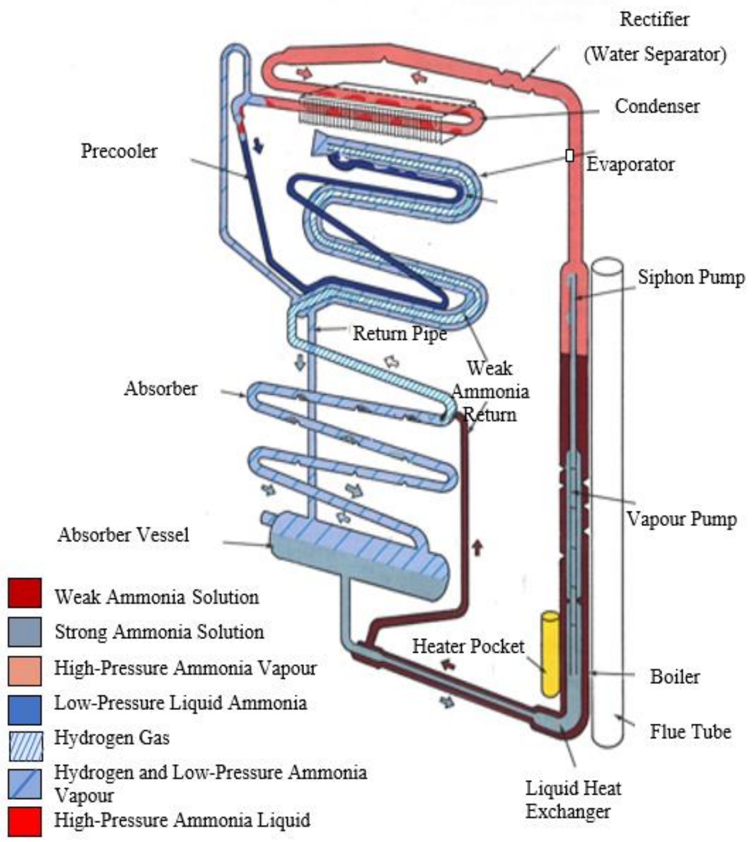


Figure 2.7 The vapour Absorption Refrigeration Cycle (Althouse et al 2004)

This vapour absorption appliance Figure 2.8 illustrates the common construction of a modern machine. Figure 2.9 Shows the cut away area of the flue tube, insulation removed, to expose the heater pipework.

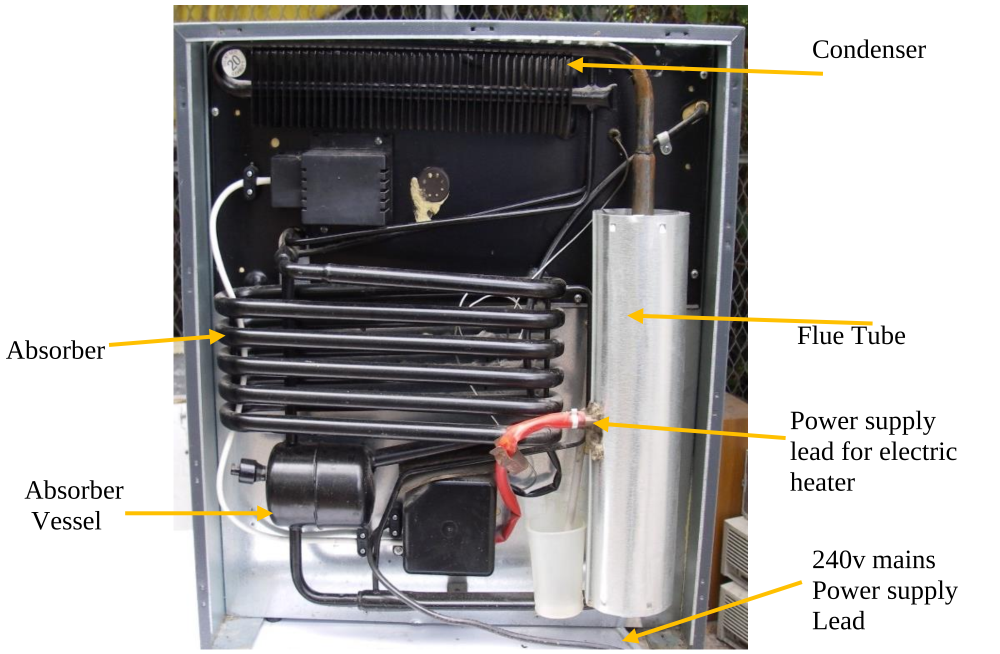


Figure 2.8 Discarded Vapour Absorption Refrigerator (Amenity site 08/2006)

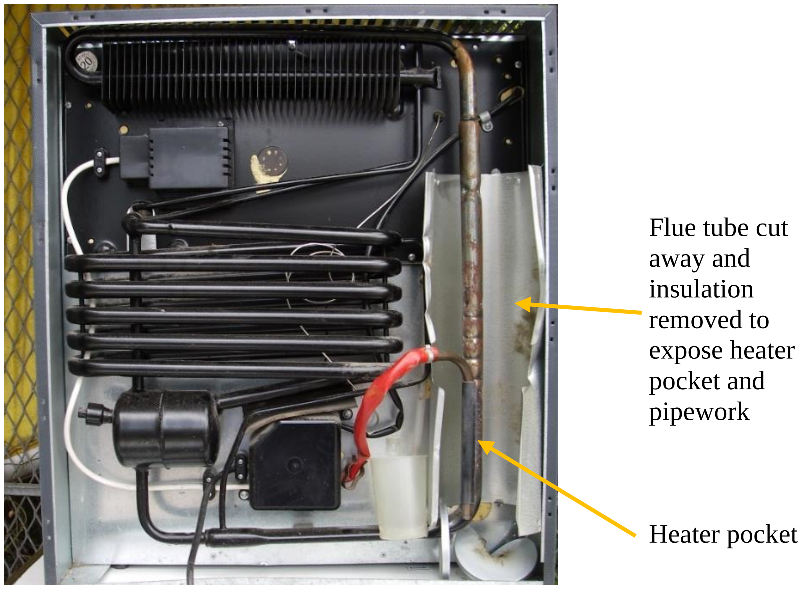


Figure 2.9 Discarded Vapour Absorption Refrigerator (Amenity site 08/2006) showing cut away of flue tube cover and removal of insulation

2.5 The future of Domestic Refrigeration

There can be little doubt that the current concerns of ozone depletion and global warming, are not already major factors in the future design characteristics of domestic refrigeration products. Energy efficiency, re-cycling and final disposal are also important considerations.

The choice of refrigerant gas has always required compromise. The required preference would ideally be

- Efficient
- Non-Toxic
- Non-Flammable
- Have a low ozone depletion potential (ODP)
- Have a low global warming potential (GWP)

The domestic refrigerator has followed a similar development path as the motor vehicle. From Poor performance, high maintenance, high cost, to mass production, efficient, low maintenance, mass ownership. Both products are now facing major challenges from environment concerns. The switch from the internal combustion engine to electric powered motor is moving forward to produce low energy emissions. Perhaps the domestic refrigerator will follow a similar change in its design, and rather than seek a compromising gas refrigerant, change the compressor for a different form of circulation pump.

One such alternative is under development in Cambridge. Described as using an energ*y* efficient and gas-free magnetic cooling *system. A* new cooling technology that use advanced metal alloys and magnetic fields to drive a novel cooling cycle*.*

The issues relating to faults and/or failures of domestic refrigerators, leading to the development of fire, appears historically to have been a rare occurrence. Whilst commercial processes have reported deaths, injuries and occasional major failures, the domestic refrigeration appliance fire is a modern issue. The switch to flammable R600a and the use of flammable blowing agents will no doubt add to the severity of the fire, but the number of recorded incidents of fires caused by a refrigeration leak is again rare.

The only common failure evidenced at the present time is the failure of the solenoid valve (See 5.7 solenoid valve failures) The solenoid valve has a history of failures. When the valve was first used, the refrigerant gas in use was R134a. The failure required the valve to be replaced but would not lead to an ignition as is now the case. It still seems that the biggest threat from fire is the construction materials rather than the refrigeration gas.

2.6 Exploding refrigerators

The first recorded refrigeration explosion by the LFB was (Fire incident no 102372041 07/2004) to a residential block of flats where a fridge/freezer appeared to have exploded around 07.30am. The tenants were asleep at the time and there were no reported injuries. The freezer section door had opened and several of the compartment trays had been forced open on the internal door surface. Several of the food items in the refrigerator compartment were wrapped in plastic, or contained within plastic bags. These showed signs of partial melting and had ‘shrink wrapped’ several items. Some of the food contents of both the fridge and freezer sections were on the floor in front of the appliance. A doorway between the kitchen and living room had been closed by a thin section of plasterboard. This board had been broken by the pressure wave, both the front kitchen windows and the rear living room windows were band the broken with glass fragments travelling several metres outside the 3rd floor flat. The appliance was removed for forensic examination. The manufacturers were invited to the examination. The resulting explosion was caused by an arcing heating element cable that had been trapped between the evaporator and the side wall inside the freezer compartment. The resulting arc damage, had melted a hole in the evaporator allowing the refrigerant gas to escape. The manufacturers confirmed that the covering over the evaporator had not been removed since its initial construction and that the trapped cable must have been made at the time of construction.

Since this incident the LFB has attended a number of incidents which resulted in explosions and blast damage. From other reported incidents around the UK, seen via media coverage and direct contact with other fire authorities, ignition of contents following an explosion is not being reported, and in most cases, initial flame wash appears to be identified from partly singed paper, labels and on some surface materials but a developing fire is again a rare occurrence.

The contents of the fridge should always be carefully checked to discount the possibility of leaking aerosol containers, providing the flammable gas rather than a refrigeration leak.

2.7 The mitigation of fire risk

The risk of fire can be mitigated in two ways. One is to reduce the probability of occurrence; the other is to reduce the consequence. Measures for mitigating appliances fires include:

- product design and selection - including selection of appropriate materials
- containment using fire resistant enclosures and compartment boundaries
- use of appropriate assembly and installation methods
- incorporation of circuit protection devices
- use of detection and suppression systems
- extensive prototype testing
- Forced failure testing.

2.8 Previous research into the fire safety of domestic appliances.

Hietaniemi *et. al* (2001) carried out an experimental study, at the VTT large fire test facility in Finland, to examine the burning characteristics (heat release rate, smoke generation) of four different types of electrical household appliance – including four tests performed on fridge-freezers. Two of the fridge-freezers tested were left freestanding, whilst the other two were located in cupboards to try to replicate the conditions of a typical domestic mounting. They found that the fridge-freezer fires exhibited by far the highest peak heat release rate of all the appliances tested - 2000 kW. These tests also had to be interrupted and extinguished because the fire grew so large it could have damaged the experimental test rig. It is therefore likely that the actual peak heat release rate, had this not occurred, would have been in excess of 2000 kW. On the basis of these test results, they concluded that such high rates of heat release would produce a very high burning rate in a room the size of a kitchen and that consequently there would be a high likelihood of flashover occurring. The origin of the high heat release rates observed in the tests were attributed to the considerable quantities of plastic used (polyurethane foam insulation, along with polypropylene and polystyrene) in the construction of the fridge-freezers tested and the nature of the design of the appliance (vertical cabinet), producing a chimney like flue, which significantly enhanced flame spread and burning behaviour.

The principal findings from their literature survey state, with the exception of burning of TV sets, quantitative information on the development of burning of electrical household appliances is scarce. Especially, no such data was found on the burning of refrigerators/freezers, washing machines and dishwashers. Some data was found on the burning of computers.

Beard and Goebelbecker (2007) describe some fire tests that were carried out for EFRA (European Flame Retardants Association) on a range of household appliances, including a single refrigerator unit. The unit had steel covers with an interior constructed from plastics - polystyrene (PS), polyurethane (PUR) insulation and polypropylene (PP). The refrigerator was ignited using an International Electrotechnical Commission, IEC TS 62441 needle flame. Fig 2.10 (safeguards to reduce the likelihood of room flash-over as a result of accidental ignition of exterior housings of audio/video and information communication technology products likely to be used in the home) The flame was applied to the right-hand side of the rear wall of the compressor compartment. The flame is to replicate an accidently caused candle flame ignition. The resulting fire was allowed to burn, without any suppression being applied, for over 30 minutes. The peak heat release rate measured during the fire test was 852 kW. On the basis of the tests, they concluded that small flame ignition sources could pose a definite risk to household appliances like refrigerators.

Figure 2.10 The IEC TS 62441 needle flame test
Beard and Goebelbecker (2007)

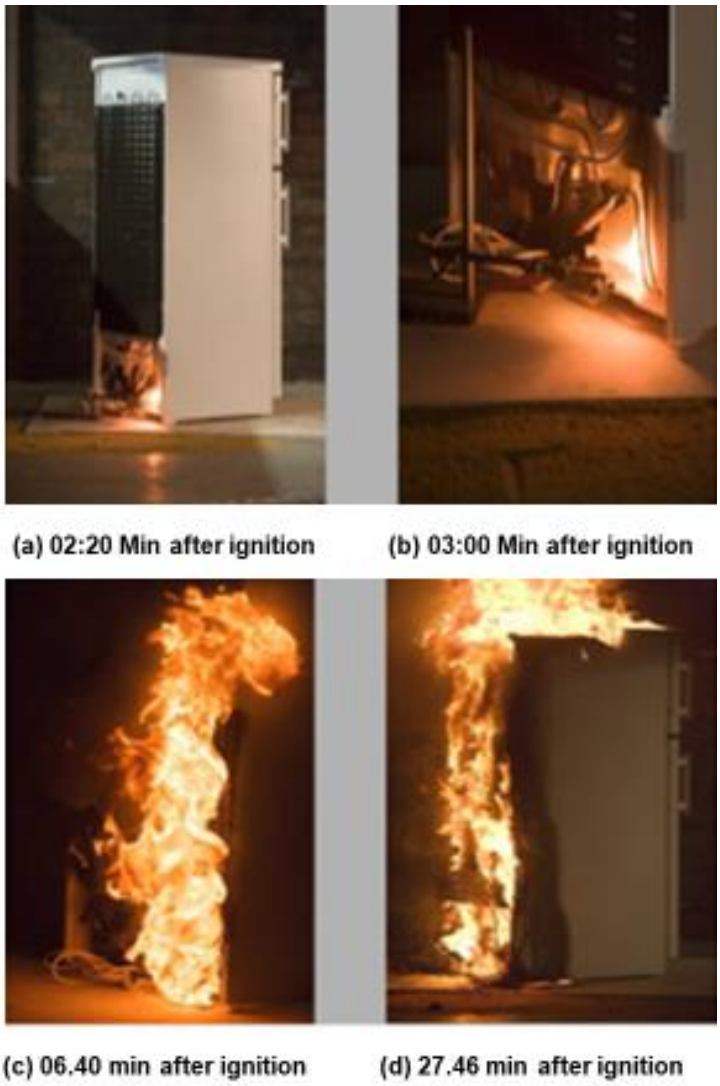


Figure 2.11 Fire sequence following ignition of fridge Beard and Goebelbecker (2007)

Hall (2012) has examined home structure fires, in the US, involving kitchen equipment (other than cooking equipment) that occurred between 2006 and 2010. The majority of these fires (59%) involved refrigerators (or separate freezers and ice makers). On average, 1,710 of these fires occurred each year, producing 2 fatalities, 56 injuries and $50 million in direct property damage per year. The majority (66%) of these fires started in the kitchen. Most of the incidents involving refrigerators or freezers were attributed to electrical or mechanical failures or malfunctions – but there were few details, if any, available on the nature of the failure or malfunction that contributed to ignition. A common issue with fire department statistics is the categorization of causes in specific failures i.e. fault with appliance, defective lead etc. This removes the specific cause which may be known and replaces it with a generic term.

Yang et al. (2013) outline a methodology which has been employed, in China, to investigate fires caused by a household refrigerator (similar in nature to the one used by London Fire Brigade fire investigators – see Chapter 3). The method considers the burning characteristics: (i) around the refrigerator; (ii) in the refrigerator; (iii) the power supply, cables and plug boards; and (iv) switch's and relays. They discuss how the analysis of fire traces –smoke and burn patterns imprinted on surrounding surfaces and objects as the fire develops and wires melted by the fire – can (providing the level of damage is not too severe) be applied to find the direction of fire spread, identify the area of fire origin and hence determine the probable cause of the fire.

In an attempt to explore further references relating to the ignition of refrigeration appliances, Babrauskas (2008) references both Hietaniemi *et. al* (2001) and Beard and Goebelbecker (2007) in his Heat Release Rates, in the SFPE handbook. Both research papers refer to the ignition of refrigeration appliances and provide details of heat release rates. He states:

> These results must not be applied to appliances used in North America, since European appliance styles are different from North American ones and also because local standards are such as to permit appliances of greater flammability in Europe.

Since American domestic appliances are often larger than their European counterparts, the expected heat release rate is likely to be greater.

European appliances would be considered easier to ignite due to the current construction methods adopted in Europe, specifically the current use of flammable back panels and the greater use of plastic components such as the evaporation tray.

2.9 Summary of fire safety

Despite the ubiquity of domestic refrigerators, relatively few studies have been made of the characteristics, causes and consequences of fires involving such systems in residential dwellings.

Previous studies have highlighted the potential importance of refrigeration fires and the very high heat release rates that they can generate. There is therefore a need for a more general study to examine the causes, consequences and prevention of refrigeration fires in residential dwellings.

2.10 The Safety of domestic appliances

Who is responsible for the safety of domestic appliances? To decide this, the first task must be to define what 'safe' means.
"Safe product" means a product which, under normal or reasonably foreseeable conditions of use, including duration and, where applicable, putting into service, installation and maintenance requirements, does not present any risk or only the minimum risks compatible with the products use had reached with the product's use, considered to be acceptable and consistent with a high level of protection for the safety and health of persons. (The General Product Safety Regulations 2005).

Most products in the UK (EU) will carry a (Conformité Européenne) CE mark. The CE marking is required for many products. It:

- shows that the manufacturer has checked that these products meet EU safety, health or environmental requirements.
- is an indicator of a product's compliance with EU legislation.
- allows the free movement of products within the European market.

The "CE" is an abbreviation of Conformité Européenne, meaning European Conformity. However, the CE mark is a self-certification scheme, which is not subject to independent checks. Hence many believe that it cannot be truly regarded as a mark of safety. (GOV.UK 2012)

Many products will also carry British Standard Institute (BSI) markings. A BSI Kitemark - trusted symbol for safe, reliable products and services. The BSI Kitemark™ is a registered trade mark owned and operated by BSI. It is one of the most recognised symbols of quality and safety and offers true value to consumers, businesses and procurement practices.

Some products carry The British Electrotechnical Approvals Board (BEAB) markings. BEAB Approved Mark demonstrates the safety pedigree of your products and a commitment to best practice, producing quality goods and to customer safety. Since the introduction of harmonised European Standards, local certification of electrical products is no longer permitted. The BEAB Mark is now owned by Intertek Group

2.11 Codes and Standards

Codes provide minimum safeguards for people with regard to safety and fire prevention. Codes protect health, safety and welfare as they relate to the residential and commercial environment. Standards are developed as an extension of code requirements. A standard is an agreed, repeatable way of doing something, a code of best practice containing technical specifications and guidelines. Thus, a code enforces compulsory conformance to a construction requirement overseen by some authority, whereas a standard sets-out a voluntary, agreed-upon level of performance. Codes characteristically use terms like "shall," "must," or "will" while Standards use terms like "can" or "may."
Codes are supplements for law and Standards are approaches to meet Code. Codes may be adopted as law, standards are legally required.

The British Standards Institute is the UK's national standards body. It oversees the production of new standards, which are harmonised with European standards. Governance of European standards is managed by the European Standardization Organizations, Comité Européen de Normalisation CEN and European Committee for Electrotechnical Standards Comité Européen de Normalisation Électrotechnique CENELEC (BSI 2017) A third organisation working towards global harmonisation of telecommunications standards is The European Telecommunications Standards Institute, ETSI.

The job of drafting full consensus standards is usually undertaken by the technical committee or subcommittee to a drafting group or panel. There are explicit rules for drafting standards that must be observed. These are intended to make sure that the standards meet their goal of providing rules guidelines or characteristics for activities for common and repeated use. The development times for standards can range from months to a number of years. British Standards usually take 12–15 months, whilst international standards can take 3 years. At national level consensus is usually required. At European and International levels consensus is sought after but the decision to progress at each stage of development is taken by majority vote.

2.12 Fire safety standards for domestic refrigeration appliances

2.12.1 IEC 60335 (BS EN 60335)

In the UK and EU, the IEC 60335 standard on the 'Safety of household and similar electrical appliances' applies. This consists of Part 1 (IEC 60335-1) which is the basic standard setting out the general requirements placed on all electrical household appliances, while Part 2 (IEC 60335-2-xx) is appliance specific and governs special features such as whether an appliance is deemed unattended or attended, the definition of the test procedures, tests concerning improper use as well as metrics including pollution degree. In the case of refrigeration appliances, the relevant standard is IEC 60335-2-24 (BS EN 60335-2-24 UK\EU) Household and similar electrical appliances - Safety Part 2-24: Particular requirements for refrigerating appliances, ice-cream appliances and ice makers.

Clause 30 of IEC 60335-1 covers the requirements for resistance to heat and fire, with clause 30.2 utilising the glow wire test. This clause specifies the requirement that non-metallic parts shall be resistant to ignition and the spread of fire. External parts which are not likely to ignite due to a heat source or flame inside the appliance do not require glow wire testing. The samples to be tested should be removed from the appliance.

In order to meet BS EN 60335-1, Section 30, a non-attended appliance (>0.2 A) such as a household fridge-freezer, samples of the non-metallic parts used in the appliance's construction are required to meet the following standard tests:

- IEC 60695-2-11 Glow-wire Flammability test for end product (GWT)
  No ignition 750°C and flame extinguish ≤ 2 s
  If > 2 s then must pass Needle Flame Test (IEC 60695-11-5) or Flammability Test (IEC 60695-11-10)
- IEC 60695-2-12 Glow-wire Flammability test for materials (GWFI)
  Test at 850°C and flame extinguish < 30 s
- IEC 60695-2-13 Glow-wire Ignitability test for materials (GWIT)
  No ignition 775°C and flame extinguish < 5 s

2.12.2 UL 250 Household refrigerators and freezers

In the US the standards controlling electrical installations in buildings and appliances are set out by Underwriter Laboratories (UL). As a building insurance company UL defines standards in order to reduce the risk of fires. In contrast the International Electrotechnical Commission (IEC), focuses primarily on the protection of persons against injury as a result of contact with live (electrical) parts. By doing this it has managed to dramatically lower the number of accidents, if not fires.

The standard applies to household refrigerators and freezers in USA and Canada and mandates the flammability testing requirements for any polymeric materials used in their construction.

In UL 250, the flammability test UL 746C (glow-wire ignitability) is used to test the resistance of polymeric electrical enclosure materials to ignition. The polymeric housing material must not support combustion for more than 60 seconds after five applications of the test flame.

The polymeric materials tendency to spread the flame once ignited in UL 250 is tested in accordance with UL Flammability Tests (adopted in IEC 60695-11-10):

a. vertical burning test to classify polymeric materials as 5VA or 5VB using UL 94
b. vertical burning test to classify polymeric materials as V-0 or V-1 or V-2 using tests defined in UL 94
c. horizontal burning test to classify polymeric materials as HB using UL 94

2.12.3 Limitations of current standards

The following requirements are taken from BS EN 60335-2- 24 2010+A2 2019 (Household and similar electrical appliances – Safety) Part 2-24: Particular requirements for refrigerating appliances:

- '*Motor running capacitors shall not cause a hazard in the event of a capacitor failure.'*

An excellent and entirely understood safety statement. It then states:
'The requirement is considered to be met by one or more of the following conditions'

- *'the capacitors are of a class of safety protection S2 or S3 according to IEC 60252-1;' (*AC motor capacitors - Part 1: General Performance, testing and rating - Safety requirements - Guide for installation and operation)

- *'the capacitors are housed within a metallic or ceramic enclosure that will prevent the emission of flame or molten material resulting from failure of the capacitor'*

From a safety stance, who could disagree with a capacitor that shall not cause a hazard. Also placing the component behind a fire resisting barrier also sounds another sensible idea. In specifying a particular capacitor type there is an obvious inference that this type of capacitor does not fail or perhaps the failure is not sufficient to produce an ignition. Capacitor failures have been an increasing fire issue throughout all white goods and given the location of almost every refrigeration capacitor, secured within the area of the compressor housing, often the housing lined with flammable insulating materials. (see Chapter 5, 5 for capacitor failures) The preferred option should be to place the capacitor in a safety housing rather than to rely on the latest technology that may follow the same failure patterns as those used previously.

Another issue often discussed within the same standard is the use of 'glow wire' and 'needle flame testing'. Glow wire testing has been used in many applications, and when used on plastics, the common result is the shrinking away from the heat of the material in direct contact. Ignition will often not take place as the surface of the material recedes and the temperature of the heat source cools. The same material will often readily ignite with flame application and the wider-spread application of needle flame testing is currently under review.

Consequential testing has also been discussed within several BSI Committees and is a further safeguard which could be explored. Whilst some components, follow a recommended testing criteria. The materials that surround and make up the construction are tested when new. The results of degradation, wear and age on materials such as fire retarded surfaces are not always considered.

Chapter 3

Methodology for investigating domestic refrigeration fires

3.1 Introduction to Chapter

The purpose of the fire investigation is to determine the origin and cause of the fire. If an appliance may have been responsible for starting a fire – then the method by which this has taken place. This chapter sets out the fire investigation procedures used by a public fire brigade, and the methodology that is used for investigating domestic appliance fires in this study. Since every fire has the potential to be a criminal event, the process followed by all public fire investigation authorities follows an almost identical path.

3.2 Fire Investigation

A Fire Investigation Officer (FIO) may be called to investigate fires in order to determine the origin of the fire, the most likely cause, defect, source of ignition, material first ignited and the material responsible for the development of the fire, as well as the gathering of information on human factors, impairments and fire safety issues. A determination of responsibility may also be required. The type and severity of the fire, it's location, casualty outcome and cause determination will determine the degree of response and the way in which the information is passed. The resulting recording process could be a series of predetermined responses through to a major report and enquiry. The information will also be reported and recorded onto the Brigades Incident Management system (IMS) with certain data supplied to the National Information Reporting System (IRS) (LFB Policy Doc 399 June 2005).

The investigation may well result in the production of a fire report or a report to a coroner for inquest. If the fire is a criminal act, police statements and reports may be required. The investigator will attempt to identify any common elements of the investigation which may be used to prevent further fires or incidents.

From the investigation of the fire, it is possible that the source of ignition is a product, or even perhaps a process. The investigator will need to determine if the fire is the result of an accidental or deliberate act, misuse or a faulty or incorrect process, component failure or incorrect construction.

Findings, results and conclusions may well be challenged. The investigator needs to be able to show his/her conclusions based on the evidence gathered and be able to show why other possible scenarios and potential ignition sources have been discounted.

3.3 Visits to local authority re-cycling yards

Part of this research project also involved regular visits to local authority re-cycling yards where permission had been given to examine refrigeration appliances, prior to their disposal. The appliances were placed in the yards for forward transfer, to be re-cycled at the designated government re-cycling centres. No history was available for any service or fault issues. The appliances covered at least the previous three decades and provided a good insight into the construction processes and material changes that have taken place. Some appeared to have been stored for a period before disposal whilst others still contained ice in areas such as the freezer section, confirming their recent use prior to disposal. It was evident that comparisons between earlier and more modern dated appliances showed a clear and progressive switch from metal and timber, to plastic construction. A difference in general construction weight was also noted with a significant reduction in more modern appliances compared to similar sized earlier examples. Where possible observations of construction materials were photographed such as figure 3.1 providing detail of changing trends. The panel located directly beneath a thin, hardboard top of this appliance has been constructed of polystyrene. The panel could be used for its insulating properties but since it contains a number of large holes, its use is probably to provide the cheapest form of rigidity to the top panel above. The material will burn rapidly once ignited and will quickly assist the spread of fire.

Figure 3.1 Polystyrene panel used in refrigerator construction.

The condition of individual components - e.g. mechanical defrost timer switches were examined and recorded and used to provide additional insight into possible failure mechanisms. When examining the mechanical defrost timer switch's, it was apparent that almost all of the switches were in pristine condition with no evidence of wear or mechanical damage apparent. This confirms the failure mode determined as water ingress detailed in section 5.4. rather than a slow, mechanical wear process. A timer switch was also found during one visit which had clearly started to fail, (Fig 5.11 Page 104) This specific switch was reported to and examined in the presence of the manufacturer.

Samples of PTC starter switches were removed and photographed from over 300 refrigeration appliances to provide a comprehensive database of compressor switches. A table summarising the different appliances with PTC switches examined is given in Appendix E This data suggested that a unless the pill retaining plates showed indication of arcing, or melting, the PTC pill was not a viable ignition source. See 5.3 Positive Temperature Coefficient (PTC) starter switch failures. It was apparent that pill failure was almost exclusive to one particular make of switch, and that the likelihood of failure to later appliances fitted with modified switch's, has not been identified.

The removal of internal covers allows access to internal components. Many of these individual parts have codes and identifiable data stamped or marked on them which may provide a link to the manufacturer. The evaporator in figure 3.2. Is located beneath a plastic (earlier metal) cover. Its surface is stamped with a manufacturer make and a date of production. The retailer states that the cost of this component together with storage limitations, prohibits long term stocking of the item, so normally the date found is within a couple of months of the production of the complete appliance. In a severe fire, the evaporator often survives due to its location, being insulated, and often in a freezing environment clearly slows the fire spread in this area. Photographing a large number of discarded appliances has become a valuable reference facility for identification of fire damaged products from incidents.

(a) **(b)**

Figure 3.2. Freezer section of a modern Fridge/freezer (a) has internal cover removed (b) to expose the evaporator and fan assembly. The steel fan cover will also be an identification flag in the debris of a severe fire. (Amenity site 09/2017)

A severe fire which has spread to the interior of this appliance. Figure 3.3. Steel fan cover can be seen in centre of melted debris.

Figure 3.3. Steel fan cover in internal debris **(**LFB Fire incident 101005091 06/2009)

3.4. Fire Investigation Methodology

Although almost every fire will be unique and require varying resources, the investigator will always be required to gather background information, photograph and record the scene and process information in order to arrive at a conclusion. During this process, developing theories and factual information may result in a change of opinion. In developing hypothesis and then testing them where possible, the investigator should be left with a conclusion based on the evidence provided.

3.5. Basic Knowledge

In order to perform and practise as a fire investigator, NFPA 1033 Standard for Professional-Qualifications-for-Fire-Investigators (2014) recommends that basic knowledge in the following topics will allow most tasks to be carried out.

- Fire science
- Fire chemistry
- Thermodynamics
- Thermometry
- Fire dynamics
- Explosion dynamics
- Computer fire modelling
- Fire investigation
- Fire analysis
- Fire investigation methodology
- Fire investigation technology
- Hazardous materials
- Failure analysis and analytical tools
- Fire protection systems
- Evidence documentation, collection and preservation
- Electricity

The list above is referred to as the 'sweet 16' list, (NFPA teaching Mnemonic) called such to assist the reader in memorising the number of listed tasks. Many of the topics overlap from one discipline to another. Some require a basic understanding, some require instrumentation and equipment, whilst others will be performed at almost every fire investigation event. It is important for the investigator to work to his/her own skill set. To know when a task is beyond their capability and also to decide if assistance should be requested. In appliance fire investigation many of our experienced investigators are entirely capable of examining, recording and processing appliances on scene. Their experience and knowledge will determine their decisions to remove and sample or to examine the product on scene. There are many other additional topics that could be added to the list for example, building construction, structural engineering and of course safety. Basic firemanship teaches many of these additional subjects so the NFPA list is the additional considerations to be added.

3.6. The Scientific Method.

In order to carry out a fire investigation, the investigator will be required to following the agreed protocols of observation, recording and processing the scene. Working from the area of least damage towards the area of greatest damage, recording, observing and photographing will take place. If the task requires a greater process than just observation, the investigator must decide either to proceed or to retain an item for further laboratory examination i.e. by x-raying or by observation with microscope. The evaluation must include the possibility of damaging the sample beyond further examination. If this is the situation, again the investigator must decide if he is suitably competent to continue further. The examination may be better carried out in a controlled environment or by someone with knowledge or familiarity of the component. It is sometimes decided that the examination may be better undertaken with representatives of the manufacturers and or insurance company in order to share the information. Since much of the public fire investigation process is designed to prevent future fires, the sharing of observation and failures is vital for future change.

The procedure carried out by LFB fire investigators follows a scientific process commonly referred to as The Scientific Method. (Figure 3.4). Hence an investigator will attempt to determine the cause of the fire (define a problem), make observations, use these to generate a hypothesis, or a number of hypotheses, then test them, and repeat the process, if necessary, until a satisfactory explanation is obtained.

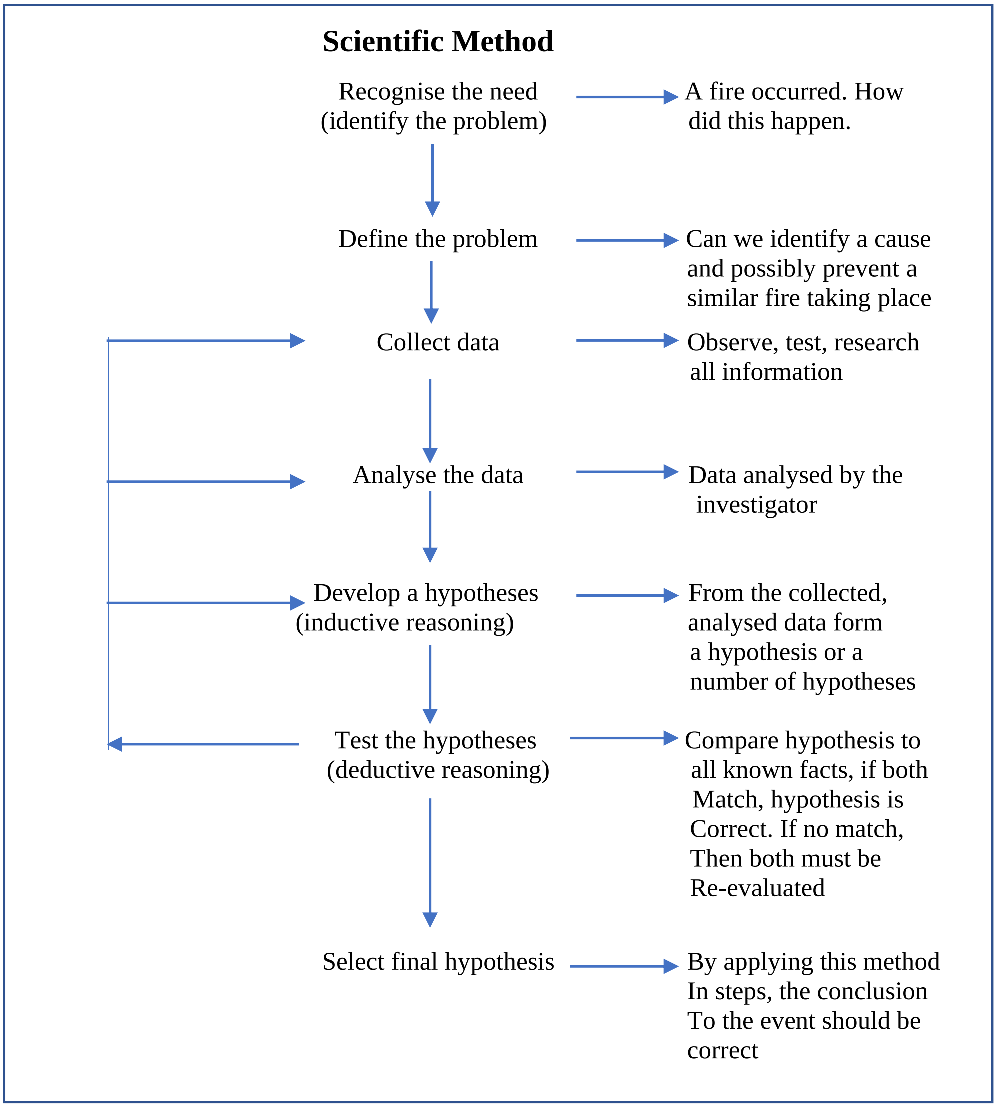


Figure 3.4. The Scientific Method (NFPA 921, 2011)

The following provides an example of the scientific process used in analysing a simple fire scene in practice:

An attendance was made to a refrigeration appliance fire. The pattern of burning clearly indicated the fire had started within the refrigeration compartment. The rear of the appliance was not damaged by fire. The possibilities initially considered was a failure of a component within the compartment, or the introduction of an ignition source. The appliance was unplugged and the occupier confirmed that it was not energised at the time of the fire. This ruled out a mechanical failure of anything within the appliance.

A search through the debris within, revealed the remains of a metal ‘tealight’ container. The occupier confirmed that they had been defrosting the appliance following a build-up of ice. The occupier had decided that the heat from the candle would speed up the defrosting process (which was correct). The cause of the fire was the result of the introduction of the candle, the only remaining decision was whether the act was accidental or deliberate. This incident was recorded as a candle fire, not a refrigerator fire. (Ref LFB Fire incident Clapham FIU Alderman)

3.7. Fire behaviour

3.8. Fire and burn patterns

Fire behaviour refers to the manner in which fuel ignites, flame develops and fire spreads. As the fire develops, grows and spreads

The investigator is attempting to determine the history of the fire that has taken place by determining how the fire patterns have been produced. The production of areas or lines of demarcation, will be dependent on differing factors which are often unique to the specific fire scene involved. The variables of materials involved, the heat release rate, the interaction of different fuel packages, the temperature of the heat source itself, the ventilation and even the firefighting will all effect the eventual scene.

The variations produced make it difficult to state definitive predictions, but some common scientific principles generally can be relied on. Kirks Fire Investigation Handbook (Dehaan, 2002 P91-92), identifies a number of general fire behavioural rules that may be applied when investigating the development of a fire. The interactions that may take place before, during and after the fire will often create contradictions to the ‘rules’.

- Hot gases and flames are lighter than the surrounding air and will tend to rise.
- Fire will always tend to burn upward in the absence of obstructions and ventilation effects.

- The fire may develop and grow as other combustible materials are involved. The greater the intensity the faster the spread
- In the absence of heat flux and more fuel close to the initial heat source, the fire may not develop and may self-extinguish.
- It is important to establish the fuel loading of the room together with the type of fuels present. The contents, also the wall, floor, and ceiling coverings. This will affect the speed and progress of the fire. Also, the resulting fire patterns may be more difficult to interpret.
- The development of the fire can be affected by variations of the air currents
- Surfaces, both horizontal and vertical may affect the path of radiated heat
- Upward fire spread is often assisted by vertical openings such as stairways, chimneys, lift shafts and ducting/cable shafts. These cavities provide further opportunity to carry the fire to other areas. The effects of ventilation in these areas may also provide additional oxygen and provide greater intensity of burning.
- Drop down, or downward fire development and spread, can take place when ignited materials such as ceiling and light fittings, wall coverings and surfaces fall or radiate to other materials below.
- Firefighting can also affect the spread of fire, both from pushing the fire into other unburnt areas and also by the effects of ventilation caused by opening/breaking or forcing entry into compartments and spaces. The effects of well-meaning occupants or passer byes, breaking windows, opening doors etc. may also provide additional oxygen for fire development

The Investigator collects data from the fire scene in order to arrive at an area and ultimately a point of origin. This data includes the patterns produced by the fire. A fire or burn pattern is defined as visible or measurable physical changes or identifiable shapes formed by a fire effect or group of fire effects. Fire effects are the observable or measurable changes in or on a material as a result of exposure to the fire. (NFPA 921 2017). There are three basic causes of fire patterns:

- Heat
- Deposition
- Consumption and degradation

Common fire patterns that are produced in most fires include:

- Mass loss of materials
- Char
- Depth of char
- Spalling
- Oxidisation
- Colour changing
- Melting
- Thermal expansion and deformation of materials
- Smoke and soot deposition
- Clean burn
- Calcination
- Breaking and staining of glass
- Heat shadowing
- Protected areas

Fire plumes will also imprint burn/smoke patterns onto the surfaces they come into contact with such as a wall or ceiling surface. These patterns seen commonly include:

- V patterns
- Inverted cone patterns
- Hourglass patterns
- U-shaped patterns
- Pointer or arrow patterns
- Circular patterns

3.9. Investigating the appliance Fire

The fire investigator will use both the physics and chemistry of fire, the identification and interpretation of fire patterns and the cause of fire growth and development to provide a broad background in which to develop skills, often from the completion of many types of fire investigations. In developing knowledge of common failures and identifying the development of fires, it is often possible to provide manufacturers and standards committees with vital information which can lead to component changes, design alterations and modifications. Manufacturers are often unwilling to provide information on specific failures although this information is often vital to effect changes.

There are limited opportunities in specialising in specific fire investigation training areas such as vehicle fires, boat and ship fires, industrial machinery, appliances etc. Whilst it is possible to study design and construction methods, this is unlikely to include any fire related information. A fire brigade investigator will gain skills from the incidents attended and this may be limited by the area that is served. Investigators vary from some serving less than a year to others with many years of service. Many of these individuals have trade training and/or qualifications in disciplines such as an electrician, mechanic, builder etc so it is common to peer review reports across the team for often expert critique.

The design and development of consumer items are constantly changing. This change produces new challenges to the manufacturer and also a need for the investigator to understand how the updated product or process works. A failure in a product or individual component may be changed through replacement or perhaps through a re-design. Over time the product may be replaced or disposed of and a totally different mechanism or process may be created, producing a change in the number, frequency and patterns of fires.

The identification of the cause of a fire, be it an appliance or another event, calls upon the same process of identification an elimination to arrive at a conclusion. It may be that a witness can describe in graphic detail the failure and ignition of an appliance. The investigator will still be required to discount and rule out other potential sources based on scientific reasoning.

In order to complete the fire incident report for an appliance fire, the following information will be required:

1. Cause/Motive
2. Source of ignition
3. Power source
4. Appliance Manufacturer (Make)
5. Model, serial number, age
6. Material/item ignited first
7. Material/item mainly responsible for development of the fire.

To obtain this information and formulate one or more possible hypotheisis as to the source of ignition and the subsequent development of the fire, the following steps in the information gathering procedure are followed:

1. Interview owner/occupier/witnesses
2. Interview firefighters
3. Examine the consumer unit (electrical supply)
4. Establish an area/room of fire origin
5. Determine if an appliance is possibly responsible for the fire
6. Indentify the failure mode leading to ignition (if posssible)
7. Use scientific analytical services to support the investigation (if required)

Note the order in which the information is collected is not fixed and can change in accordance with the circumstances and requirements of the incident.

3.10. Interviewing Witnesses.

The investigator will interview any witnesses to the fire and ask them to describe the incident. They will be asked about any observations made at the discovery of the fire i.e. had the lights/electricity failed. Was smoke/fire seen in any specific area? Did the witness observe flames/smoke coming from the appliance? If the involvement of an appliance is suspected, the following background questions will also normally be asked of the owner/occupier and any evidence to support the findings will be recorded:

1. Any maintenance/repair or service history Any documentary evidence?
2. Any previous or recent issues with the working of the appliance such as freezing or defrosting issues?
3. Any recent interaction with the appliance, change of settings etc.
4. Had the appliance emitted any unusual noises? If so what type of noise? Constant loud humming? A sudden noise or bang?
5. Any evidence/reports of rodent activity in the property?
6. Had the appliance recently been moved?
7. What was the estimated age of the appliance?

A simple question such as the make, model and age of the appliance can result in a wide spectrum of answers from a distraught owner. It is often the case that the make and model details are incorrect and the age provided is often many years out from the eventual establish age. To aid recall, it is worthwhile suggesting the recollection of an event such as the re-modelling of the kitchen, or when the person moved to the property and also confirming if the appliance was second hand or new when purchased. The type of refrigerant gas recorded on the serial plate and on the compressor will also provide a broad date timeline for the product. If available, the details recorded from the make and model of an appliance can provide a range of dates from start to end of production. The serial number of many manufactured appliances also provides a recorded, specific date of production.

Note that when gathering any information, it is often the case that the owner/occupier may be severely stressed, concerned and confused. Sometimes the requested information can have additional consequences for the person answering and so it may be incorrect. Single witness information, although always requested, should therefore be viewed with caution and where possible corroborated by further witnesses.

3.11. Information from Firefighters.

A fire-fighter attending a fire incident will probably be faced with an unfamiliar building, perhaps distressed members of the public and a fire situation that may involve the possibility of rescues, dangerous structures, chemicals and many other hazards. The decision of where to enter and when to attack the fire or attempt to locate victims, are often all seen through the face-mask of a breathing apparatus. From the initial arrival, through all the actions normally carried out thereafter, the process will continue until either relieved, or the task is completed. Whilst carrying out fire-fighting operations, disturbance and further destruction of the scene is often inevitable.

It should be remembered that following this dramatic process, the fire-fighter may also be a victim and should be treated by the investigator in the same way that other witnesses are treated. Through careful questioning, avoiding leading questions and where possible carrying out the questioning individually rather than in a group setting, valuable information may be obtained.

The fire-fighter can often provide information on the development of the fire, where flames or smoke where seen, how and when the fire spread, where it was first seen or located and what disturbance has taken place since their arrival. The information may include specifics of exact location, and the size of fire when first seen together with the details of extinguishment and what further disturbance may have been required to fully extinguish the fire.

3.12. Examining consumer units (electrical supply)

The position and condition of circuit breakers and fuses are almost always recorded and photographed as part of the investigation. Fire-fighters will often locate the consumer units and isolate both gas and electric supply. They are encouraged to avoid disturbance of individual switch’s and if possible, use the isolation of the main on-off switch. It is not always possible for observation during fire-fighting and in some cases the isolation of every individual switch is completed. As the position of these switch's is normally one of the most common questions asked by the investigator, many fire-fighters will make a mental note of the positions and actions when found.

3.13. Establishing an area of origin

When a fire develops it may damage and consume combustible materials in close proximity. This may leave fire patterns on the materials and also develop patterns from both heat and smoke generated by the combustion process. The availability of oxygen will also determine the rate and size of fire spread, but as this process continues it leaves patterns and indicators that the fire investigator can often interpret. Initially the area of origin may be readily defined, particularly if the fire has been confined. It may be defined as an object, a small area, a room or perhaps a floor within a building until further information and observations can accurately determine a defined area. The modern construction of almost all domestic refrigeration appliances rarely allow a fire that has developed as a result of a failure or defect to lead to smouldering and in most cases when the fire contacts the insulating materials, a rapid-fire development takes place. On a few occasions the resident may be able to extinguish the fire if attacked quickly but generally the development of the fire is inevitable once the insulation is involved.

The identification of the area of origin may initially be determined using eyewitness accounts, CCTV or through the recording of the fire by mobile phones or devices of any bystanders. With many appliance incidents, the resulting fire will provide burn patterns to adjoining materials and surfaces, often clearly identifying the appliance as the potential ignition source. Having recorded the observations leading to this determination, the investigator will then examine and record the resulting damage and remains. A determination to examine or sample will then be made. If the decision to sample is made, physical disturbance of the appliance should be kept to an absolute minimum, in order to provide the maximum detail to the examiner. Having recorded the patterns on all external surfaces and ensuring the examination of all surrounding debris, the appliance is often wrapped in a cling-film plastic covering in order to prevent any loss of evidence during transportation.

3.14. Determining if the appliance is responsible for the fire

Is the appliance located in the area/room of fire origin? If so, the appliance should be checked to see if it was in operation at the time of the fire – was it plugged in and the socket switched on? Everything should be photographed in position before moving or disturbing the appliance. The appliance should be photographed firstly from the front and the sides and then from the rear.

The level of damage to the appliance and the location of damage should then be assessed. More highly damaged areas should be identified. Is there damage to the compressor housing at the base of the appliance? Is there a V burn pattern spreading up the back and/or sides of the appliance and/or surrounding walls or objects indicating the direction of fire/smoke spread?
Is there damage to the interior of the appliance, that may indicate the fire started within? If possible, the use-by and best-before date on any food labels inside the fridge/freezer should also be examined to indicate if the appliance was in use at the time of the fire.

Based upon the available evidence, a judgement may then be formed by the fire investigator as to whether the appliance represents a credible ignition source and the most likely source of ignition for the fire (when compared to the other alternative ignition hypotheses).

3.15. Identify the failure mode leading to ignition

Over the course of investigating a large number of domestic refrigeration fires, in London, a number of specific failures modes leading to ignition have been identified: starter relay failure; PTC switch failure; mechanical defrost timer switch failure; capacitor failure; cut-out switch failure (integrated units); solenoid failure; and rodent activity. See Chapter 5 for further details, describing the nature of the different failure modes leading to ignition of domestic refrigeration appliances and how they can be identified. If possible, the investigator should examine the appliance and the remaining components to see if a specific failure mode can be identified and if the pattern of burning exhibited is consistent with the suspected failure mode. The specific identification of a failure will be a critical feature should the manufacturer be required to carry out any future risk assessment of the product. Any vagueness or uncertainty over the cause, may allow the manufacturer to disregard the incident unless a defined cause has been reached. It is also important to be able to confirm what hasn't called the fire, so by checking the areas of common failures, you are re-enforcing your final conclusion.

3.16. Electrical fire causes in appliances.

The following electrical failures may be considered as ignition sources in refrigeration fires.

- Resistive heating
- Arcing, sparks and/or short circuiting
- Overcurrent/overloading.

Abnormal electrical activity may produce characteristic damage that may be recognised on conductors, contacts terminals and wiring. (NFPA 921 Chapter 9 2017).

This can be further broken to down to provide a list of potential ignition causes, some regularly identified in domestic refrigeration fire incidents:

- Poor connections
- Arcing across a carbonised path
- Arcing in air
- Excessive thermal insulation
- Overload
- Ejection of hot particles
- Dielectric breakdown in solid or liquid insulators

3.17. Using analytical services

Bureau Veritas (BV) are contracted by the LFB to provide (along with other services) a 24 hour on call scientist who will be able to assist in the examination, and/or provide technical assistance to the Fire Investigation Teams (FIT's). Depending on the complexity and type of examination required, the FI will either sample items or request the scientist to attend the scene. The determination for assistance rests with the FIT operative. BV can provide a full laboratory examination of a sample including x-ray, microscopic and gas chromatograph (GC) sampling techniques.

At the fire scene, BV assistance is often utilised when a sample, such as an industrial process machine or large component, or an actual process cannot be sampled or removed. They may also be requested to attend if the moving of a sample may result in its destruction, or severe disturbance of the remains may take place following removal.

If it is considered that there are any doubts in the determination of an appliance's involvement, the appliance can be sampled and taken to the forensic science laboratory for more detailed examination and possible x-ray analysis. Further research into the particular make and model of appliance may then also be carried out. In London, if an appliance is sampled, both insurance companies and the appliance's manufacturer (or their agents), are given the opportunity to attend the scientific examination process. Trading Standards are also informed of the resulting incident details.
If the investigator has no access to x-ray facilities or is unsure that by dis-assembling the sample appliance, destruction of components may occur, the consideration to leave the sample for other agencies should be considered.

3.18. Uncertainty over appliance involvement

It is not unusual for the severity of a domestic refrigeration fire to prevent the specific identification of a single component failure. The two most common hypotheses will be either an introduced ignition source or a component failure. An introduced ignition source will be either an accidental event or a deliberate one. It is often possible to confirm or exclude these by elimination, leaving only an occurrence involving the appliance itself. Since self-heating of the materials of construction is normally ruled out, the only remaining possibilities are the introduction of an ignition source, or a failure of an electrically, energised, component. Many component failures, and ignition of materials such as stored LPG in containers, leave identifiable, repeatable, evidence but which may require the examination to be conducted in the laboratory rather than at the scene. It is often the case that the pattern of burning suggests an ignition source that is either close to or within the compressor compartment at the rear. With careful examination, each potential ignition source can be either confirmed or eliminated. There are also incidents recorded where the specific item of failure has not been identified but where the investigator is still confident that the fire originated within the compressor housing. The term ‘most likely’ is often used to describe this specific uncertainty.

In some cases where the cause is not specific, the determination may be partially recorded with certain elements recorded as undetermined. With refrigeration products, the identification has proven to be difficult following many incidents that have suffered severe fire damage making even the identification of some appliances an impossible task.

The location of the compressor in almost all domestic refrigeration appliances is to the rear of the appliance at floor level. The resulting compressor housing area, a 4-sided open box shape, commonly lined with polyethylene/ polypropylene twin-wall sheet covering to the top and rear wall surfaces, plastic, polystyrene or uncovered metal panels to the side walls, a large plastic evaporation tray together with almost all the most common components that may fail and provide an ignition source. Once the fire is initiated within this confined area, rapid development normally follows with all components and surfaces contributing to a rapidly developing fire. It is also common to find one of the refrigerant gas pipes, or the filter/dryer has failed, allowing escaping gas to ignite and contribute to the fire loading. The most common scenario following many refrigeration fires is the inability to be able to conclusively exclude every component due to severity of damage. It is then that the experience of specific failure mode identification is required and every potential ignition source is examined.

Figure 3.5. shows two different fridge/freezers ((a) Fire incident no 110421511 01/2015 (b) Fire incident no 57851131 05/2013) exhibiting similar burn patterns following a failure of a component within the rear compressor compartment. The circular burn pattern close to the floor results from a combination of direct flame impingement, radiant and convective heat transfer and conduction (Superposition). The white circular pattern of unburnt panel directly above is formed due to the cooling effect of the freezer compartment restricting the rate of burning into the appliance. The pattern is common when the fire has developed or reached the compressor compartment and is caused by a variety of initial failure modes.

(a) (b)

Figure 3.5. (a) and (b) exhibiting common burn patterns.

Another example, figure 3.6. with similar burn pattern but a less intense fire. This fire was caused by the failure of the run capacitor.

Figure 3.6. Further example of familiar burn pattern. (LFB Fire incident no 77514081 05/2008**)**

The filter/dryer is often found to have ruptured on the inner face as Fig 3.7. towards the fire's location. The escaping refrigerant gas is likely to add to the intensity of burning within the compressor compartment.

Figure 3.7. The fire within this compressor compartment has resulted in the rupture of the filter dryer, commonly forming a heart shape with the expanded metal case. (LFB Fire incident no 81120101 05/2010)

3.19. An example illustrating the fire investigation process

The following example illustrates how the procedure outlined in section 3.5 is applied in practice. A house fire was reported to LFB by a passer-by who noticed smoke issuing from a front window. (LFB Fire incident number 61217071.04/2007) The fire crew confirmed their actions on arrival and provided detailed observations of the scene. Both the front door to the house and an internal door were forced open by firefighters. The fire was located in one corner/side of the bedsit room.

. The status of the electrical supply at the fire scene indicated both the TV and the refrigerator plugged into the wall socket; the tripped switch on the consumer unit relating to the ground floor socket circuit.

The occupants were confirmed as being out at work by neighbours. A cardboard box containing a television set and a suitcase were stored on top of a refrigerator. Both had been partially damaged by the fire. A second television set was located on top of a small cupboard/stand adjacent to the refrigerator (right side). Both this TV set and the refrigerator were plugged into the wall socket and switched on (down position) (Figure 3.8.)

Figure 3.8. Wall socket showing plugged in appliances.

The consumer unit indicated that the circuit protecting the socket outlets to the room had either tripped or was previously operated. (Figure 3.9.). There were unlit candles placed on an adjacent table. No evidence of smoking materials was found

Figure 3.9. Electrical consumer unit showing one circuit breaker operated.

A small bedside cabinet was located next to the refrigerator (left side). The cabinet was moved to reveal a burn pattern matching that found on the side of the refrigerator (Figure 3.10 When the refrigerator was moved, a level of burning was observed to the rear. (Figure 3.11.) Burning to base of the refrigerator was also observed along with a burn pattern to the adjacent wall surface.

Figure 3.10. The burn patterns observed on the refrigerator and the surrounding objects and surfaces including the adjoining cabinet.

Figure 3.11. The refrigerator has been moved forward to reveal the damage to rear wall surface and floor beneath.

Figure 3.12. With the refrigerator removed, the remains of a base polystyrene and cardboard packing tray is observed. Packing materials are commonly found left in situ by owners', often years after installation.

Figure 3.13. The floor beneath the refrigerator has been removed to check for any fire spread and confirms that the fire originated above the floor surface.

Figure 3.14. Pattern of burning to wall surface behind refrigerator

Figure 3.15. Refrigerator in rear garden, Contents and damage to appliance observed.

Figure 3.16. Rear of appliance showing low level fire damage and spread through compressor compartment

Figure 3.17. Close up of compressor positive temperature coefficient (ptc) switch showing side wall of pill

The investigator recorded the scene and then removed the appliance to the garden. An internal view of the refrigerator confirmed that the appliance was in use at the time of the fire. The area of origin was clearly the refrigerator.

The final decision was to determine the item that had ignited first and to decide if the evidence was sufficient to identify the component/method of failure (failure mode). In this case the specific failure mode was determined to be the compressor switch.

3.20. Appliance failure data

Details of fire causation within fridge and freezers are difficult to obtain. Many recorded fires are placed under the umbrella of electrical faults (fault, defect in appliance) which just about covers any event. Fire damage often results in little evidence remaining so electrical fault sounds quite acceptable for an ageing, well used appliance. Reference books containing details of components may often list generic designs and often lack detailed information of specific construction. Whilst repair engineers will be able to confirm failures of components, in general they do not attend appliances once they have caught fire as repair is normally impossible. Manufacturers are often reluctant to admit any failure issues and will rarely pass information on failures or problems unless the product has been officially classified as requiring a recall or more commonly a safety notice. Passing information to the fire brigade is often refused as the information is classified as commercially sensitive. The LFB investigator will be able to interrogate the Brigades information recording system (IMS), the national fire data system (IRS) will require a formal request for information of any other incidents where the same make/model and details are held. This process is often just the start of a continuing process. If a component is fitted to multiple models and even different makes, the identification of a continuing pattern is difficult. The detailed report and information gathered may well form part of the next investigation should a similar event occur.

Recall information is widely available on the internet and often from the manufacturer although details of the specific failure may not be available for public viewing. Although an appliance may be subject to a known fault and or recall, it is quite possible that the cause of the specific fire being investigated is actually another developed fault.

3.21. Fire data analysis

In order to determine the underlying statistical characteristics of fires caused by faults/defects occurring in domestic refrigeration systems (refrigerators, freezers and fridge-freezers) in residential dwellings and allow a comparison to be made with fires caused by other types of domestic "white goods" appliances (dishwashers, washing machines and tumble dryers) the following data sets have been used:

(i) DS-1: London Fire Brigade IMS data for appliance fires in London 2011-2015

London Fire Brigade (LFB) record data about the fires they attend into the LFB Incident Management System (IMS). The IMS meets the requirements specified for the UK government's national Incident Recording System (IRS), which LFB adopted in 2008.

The IMS data set used for the study contains data recorded about the appliance fires, attended in Greater London by LFB, over the five-year period from 2011 to 2015. The analysis was restricted to "white goods" appliance fires involving - fridge/freezers, dishwashers, washing machines and tumble dryers that occurred in residential dwellings, where the main cause of the fire was determined to be a "fault in equipment or appliance".

(ii) DS-2: Home Office IRS Incident level domestic appliance fires data set for England (and London) 2010/11 to 2015/16

This (incident level) data set issued by the UK government (Home Office) is for primary dwelling (i.e. residential household) fires recorded into the

Incident Recording System in England, where the ignition source was identified as a domestic appliance (Home Office 2016). The data collected is based on financial years running from 1st April to 31st March running from 2010/11 onwards over a six-year period. The analysis performed here was restricted to a subset of appliance fire incidents involving fridge/freezers, dishwashers, washing machines and tumble dryers, where cause of the fire was determined to be "faulty appliances and leads". This data set also allows subsets of incidents for specific regions, including London, to be selected for analysis.

3.22. Personal investigation skills

The identification of the make of appliance is vital to ensure that the failure can be attributed to the right manufacturer. Without this detail, the process for corrective action is almost impossible. Modern appliances often at best have paper or plastic identification labels. Even without a fire event, it is not unusual to find the identification label within the fridge to have been completely worn away through abrasive cleaning of its surface. The LFB have campaigned for many years for better identification marking. We will often be contacted by other Fire Authorities who are also unable to determine makes following serious fire incidents. An encouraged process within the LFB fire investigation unit is to ensure that the appliance involved is completely photographed from every side (inside and out). If possible both top and base included. It is easy to be drawn to a particular area, for example if the fire is obviously confined to the rear compressor area, why photograph the undamaged areas. This process has multi-benefits.

- It shows that the investigation has been thorough.
- It provides evidence why other potential ignition scenarios have be discounted.
- It provides a database of incidents and investigations for comparison.
- It provides a comparison of features and construction methods.

One of the most common construction similarities is the steel plates that are used to hold the condenser frame to the rear of the appliance. Figure 3.18. Shows a collection of brackets from different manufacturers, all logged and available for comparisons. These plates are individually designed by each manufacturer. All of a slightly different design and many using unique fixings. The mounting holes, are often unique.as are the variation of bolts and screw fixings used. Since they always survive the fire, and are often undamaged or unaffected by the fire, they provide a possibility of identification. Hinges, frame, mountings, base wheels or feet are all often survivors of the fire. Many of the frame mounts are predrilled and used for a number of functions by individual companies allowing for common identification. Finally, the area of the base is often neglected when photographed. The under frame again is often uniquely drilled and is perfect for cross identification with other recorded appliances. This data is now stored to create a library of information. It is often interrogated for both LFB incidents and enquiries by other Fire Authorities in serious or fatal fire incidents.

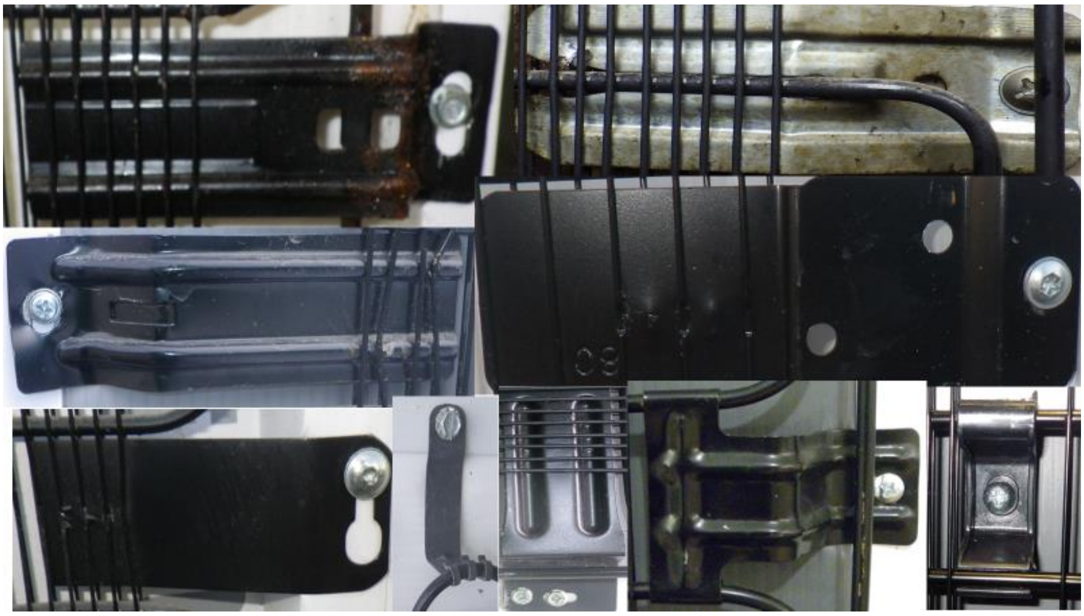


Figure 3.18. Showing variations of condenser bracket design.

3.23. Summary

Through the recording of details from fires over previous years, LFB fire investigation has provided access to the specific details of many case histories for incidents involving domestic refrigerators. Many of the incidents have resulted in samples being removed and examined by forensic scientists. By employing the methodology described in this chapter, the information collected from the scene of fire investigations involving domestic refrigeration appliances over the past decade, has been used here (see Chapters 5 and 6) to identify possible ignition and fire spread mechanisms occurring in fridge and freezer fires.

Chapter 4

Analysis of Domestic Appliance Fire Data

4.1 Introduction to Chapter

As discussed in Chapter 1 it has been suggested that, largely on the basis of reports from fire investigations, fridge/freezers can present a significant fire risk resulting in injuries/fatalities and producing significant levels of property damage. Specifically, it has been postulated that fridge/freezer fires:

- Are a significant cause of fires in domestic premises
- Are often of greater severity than other comparable domestic white goods appliances – having more chance of spreading beyond both the appliance and the room of origin

A statistical analysis of the available residential dwelling fire data (for the UK – Great Britain, England and London) has therefore been carried out, in this chapter, to identify characteristic statistical features and put this to the test. In particular, a comparison has been made between the characteristics (i.e. frequency and consequences) of fires caused by faults in fridge/freezers and fires caused by faults in other comparable types of domestic “white goods” appliance (washing machines, dishwashers and tumble dryers).

4.2 Number of appliance fires by year

Table 4.1 shows the number of dwelling fires caused by faults in the four different types of appliance that occurred each year in London from 2011-2015 (DS-1). The results suggest that for each type of appliance there are a roughly similar number of incidents occurring each year e.g. around 50 fridge/freezer fires per year, illustrating the persistent/chronic nature of the problem.

Table 4.1. The number of fires each year, by white goods appliance type, for residential dwellings in London.

Ignition Source	2011	2012	2013	2014	2015	Total
Dishwasher	51	34	51	49	21	206
Fridge/Freezer	52	53	45	30	50	230
Tumble Dryer	36	37	45	61	29	208
Washing Machine	68	88	72	79	80	387

Based on DS-1: Appliance fires in residential dwellings in London, 2011-2015, where the cause was attributed to a fault in the appliance.

Table 4.2 provides a similar breakdown of the number of dwelling fires caused by faults in the four different types of appliance for England for the six years from 2010/11 to 2015/16 (DS-2). A similar pattern of occurrence is observed.

Table 4.2**.** The number of fires each year, by white goods appliance type, for residential dwellings in England.

Ignition Source	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	Total
Dishwasher	359	379	343	354	314	219	1968
Fridge/Freezer	240	262	244	227	238	192	1403
Tumble Dryer	398	339	435	360	433	440	2405
Washing Machine	513	461	448	440	454	449	2765

Based on DS-2: Appliance fires in residential dwellings in England, 2010/11-2015/16, where the cause was attributed to faulty appliances and leads.

4.3. Fire frequency and casualty rate

Table 4.3 provides a breakdown (using DS-1) of the number of fires, injuries and fatalities (and the casualty rate per 1000 fires) for each of the different types of white goods appliance that occurred in residential dwellings in London 2011-2015 (where the cause was attributed to a fault in the appliance). In terms of crude numbers, it is evident that the largest number of fires were caused by washing machines in contrast, from table 4.3. fridge-freezers were responsible for the largest number of fire related injuries – significantly more than for the other types of appliance – whilst washing machines were found to be responsible for relatively few injuries – despite having the highest incidence of fire. Fridge/freezers were also the only type of appliance in the data set found to be responsible for causing fire related fatalities (8 deaths) during the period considered.

Table 4.3. The number of fires, injuries, fatalities and casualty rate, by white goods appliance type, for residential dwellings in London.

Ignition Source	Fires	Injuries	Fatalities	Casualty rate (per 1000 fires)
Fridge/Freezer	230	69	8	335
Dishwasher	206	46	0	223
Tumble Dryer	208	37	0	178
Washing Machine	387	13	0	34

Based on DS-1: Appliance fires in residential dwellings in London, 2011-2015, where the cause was attributed to a fault in the appliance.

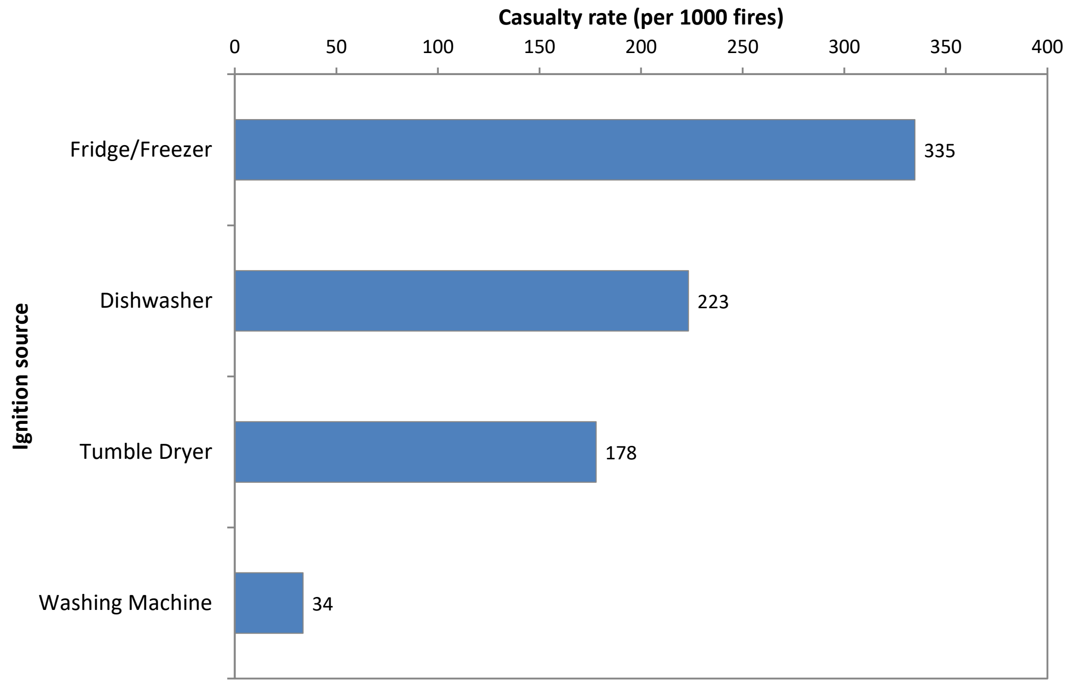


Figure 4.1. The different types of appliance ranked in terms of casualty rate per 1000 fires.

Figure. 4.1 shows the different types of appliance ranked in terms of casualty rate (per 1000 fires). Fridge-freezers fires produced the highest casualty rate significantly higher than for fires caused by both dishwashers and tumble dryers. At the other end of the scale, washing machine fires exhibited a much lower casualty rate (an order of magnitude lower than that found for fridge-freezers).

4.4. Fire spread

The IMS data set, DS-1, for appliance fires in London includes a field “At Stop Damage Spread Size” which groups the level of fire damage at the point the fire was stopped into several different categories. Using this data, it is possible to determine the number (and percentage) of fires that spread beyond both the first item ignited and the first room and hence provide a simple measure of the level of damage caused by each type of appliance fire.

Table 4.4. The percentage of fires spreading beyond the first item ignited, by white goods appliance type, for residential dwellings in London.

Ignition Source	Fires limited to the item 1st ignited	Fires spreading beyond 1st item	% of fires causing damage beyond 1st item
Fridge/Freezer	46	167	78%
Dishwasher	81	105	56%
Tumble Dryer	91	96	51%
Washing Machine	236	72	23%

Based on DS-1: Appliance fires in residential dwellings in London, 2011-2015, for incidents where the cause was attributed to a fault in the appliance and "At Stop Damage Spread Size" was recorded.

Table 4.4 summarises the number of fires both limited to and spreading beyond the first item ignited, whilst Figure. 4.2 shows the different appliance types ranked in accordance with the percentage of fires spreading beyond the first item ignited. It can be seen that the majority of fridge-freezer fires (78%) spread beyond the first item. Around half of the dishwasher (56%) and tumble dryer (51%) fires spread beyond the first item. In contrast less than a quarter (23%) of the washing machine fires spread beyond the first item.

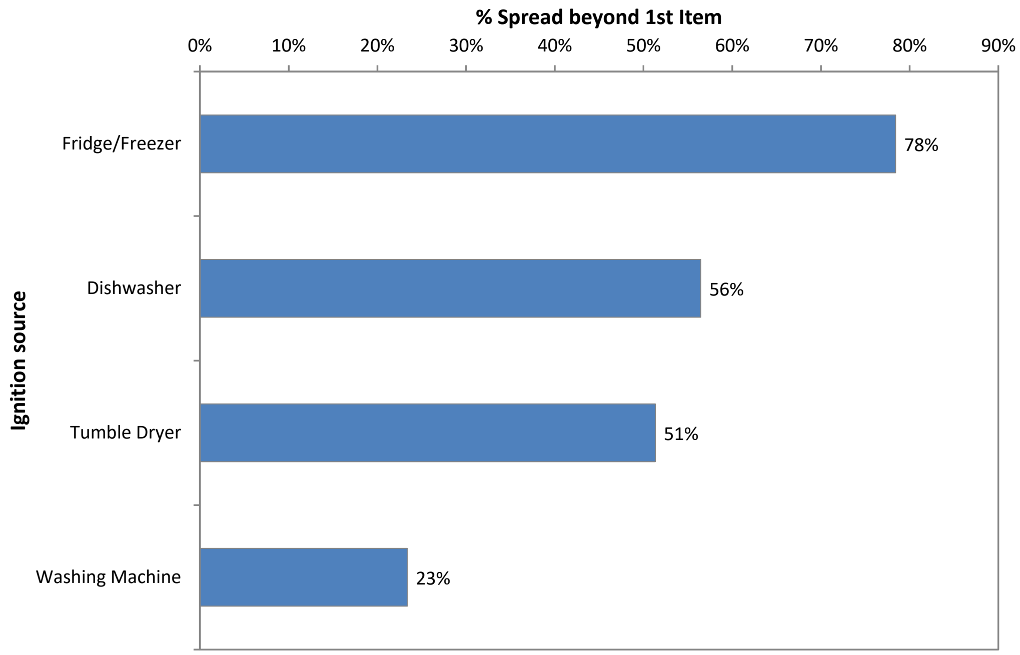


Figure 4.2**.** The different appliance types ranked in accordance with the percentage of fires spreading beyond the first item ignited.

Table 4.5**.** The percentage of fires spreading beyond the room of origin, by white goods appliance type, for residential dwellings in London.

Ignition Source	**Fires limited to the Room of Origin**	**Fires spreading beyond the Room of Origin**	**% of fires spreading beyond Room of Origin**
Fridge/Freezer	129	84	39%
Tumble Dryer	149	38	20%
Dishwasher	172	14	8%
Washing Machine	291	17	6%

Based on DS-1: Appliance fires in residential dwellings in London, 2011-2015, for incidents where the cause was attributed to a fault in the appliance and "At Stop Damage Spread Size" was recorded.

Similarly, Table 4.5 gives the number of fires both limited to and spreading beyond the first room, whilst Fig. 4.3 shows the different appliance types ranked in accordance with the percentage of fires spreading beyond the first room. Once again fridge/freezers are ranked highest with 39% of fires spreading beyond the room of origin. Tumble dryers are ranked next highest with 20% of fires spreading beyond the room of origin. However, only a small proportion of the fires caused by dishwashers (8%) and washing machines (6%) spread beyond the first room.

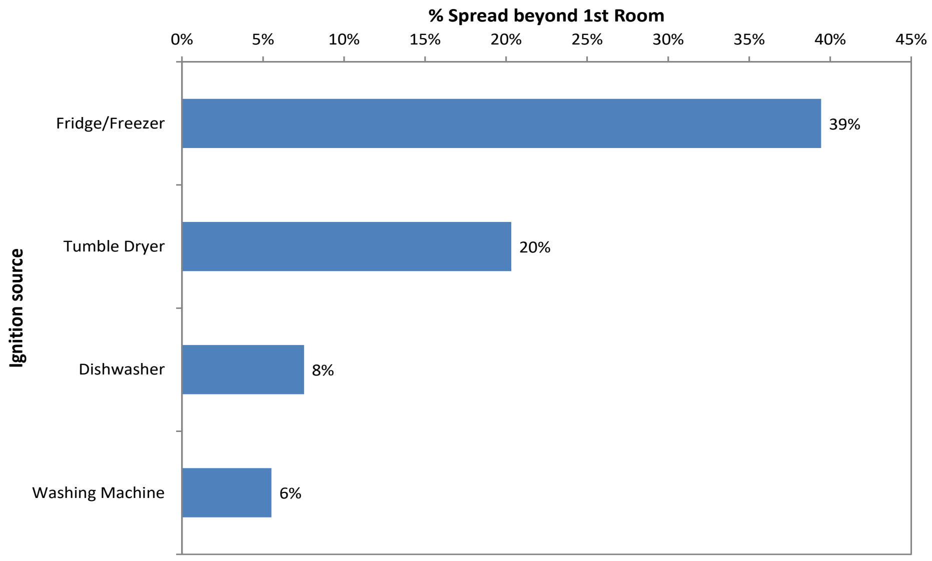


Figure 4.3. The different appliance types ranked in accordance with the percentage of fires spreading beyond the first room.

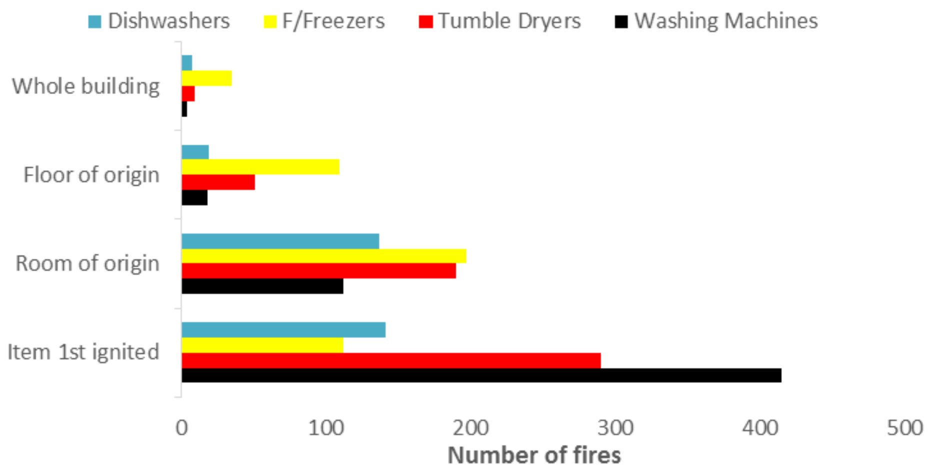


Figure 4.4. Number of domestic appliance fires in London categorised by degree of fire spread and appliance type.

Fig 4.4 breaks down the number of appliance fires recorded in London (2008 – 2015) by appliance type and degree of fire spread. Comparing the four different appliance types, the results suggests that refrigeration fires result in the greatest risk of fire spread following ignition. Thus, although there were more washing machine fires overall, most remained localised to the first item ignited. By comparison a far greater number of fridge/freezer fires spread beyond the first item, to affect the room and floor of origin and the building as a whole.

4.5 Fire damage area

The UK Home Office incident level domestic appliance fires data set for England (DS-2)-Appliance fires in residential dwellings in England, 2010/11-2015/16 includes the field "FIRE_DAMAGE_EXTENT". This records the total horizontal area damaged by the flame and/or heat (in m^2) at the stop of the fire and is divided into ten different categories (0, Up to 5, 6 to 10, 11 to 20, 21 to 50, 51 to 100, 101 to 200, 201 to 500, 501 to 1000, Over 1000).

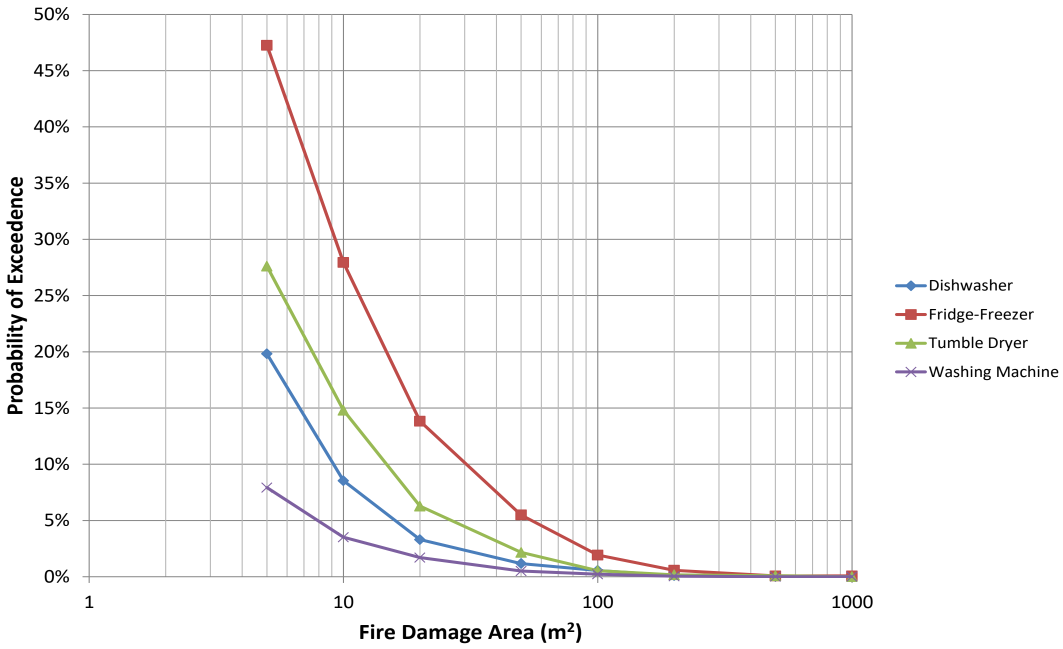


Figure 4.5. The CCDF for fire damage area, exhibited by different type of white goods appliance, for residential dwelling fires in England (DS-2). Each distribution gives the probability of fire damage exceeding a given area.

Based upon this data, Fig 4.5 shows the complimentary cumulative distribution function (CCDF) for fire damage area that is obtained for each type of appliance (the CCDF gives the probability of a fire exceeding a particular fire damage size). From this it is evident that fridge/freezer fires are most likely to exceed a given fire damage area, followed by tumble dryer, dishwasher and with washing machine fires being the least likely.

Table 4.6. The percentage of fires with damage extent greater than 5 m^2, by white goods appliance type, for residential dwellings in England.

Ignition Source	Fires with damage extent ≤ 5 m^2	Fires with damage extent > 5 m^2	% fires with damage extent > 5 m^2
Fridge/Freezer	740	663	47%
Tumble Dryer	1741	664	28%
Dishwasher	1578	390	20%
Washing Machine	2546	219	8%

Based on DS-2: Appliance fires in residential dwellings in England, 2010/11-2015/16, where the cause was attributed to "faulty appliances and leads".

Based upon this data, Table 4.6 summarises the number of fires, for each type of appliance, causing a fire damage area of 5 m^2 or less. It also gives the number and percentage of fires with damage exceeding 5 m^2 in extent. Whilst half of fridge/freezer fires (47%) had a fire damage area greater than 5 m^2, only 28% of the tumble dryer fires and 20% of the dishwasher fires had a damage area extending beyond 5 m^2. In contrast only a small fraction (8%) of the washing machine fires resulted in damage in excess of 5 m^2. These results appear to be broadly consistent (and display the same appliance rank ordering) as those found from the DS-1 dataset for London, for fires spreading beyond the first room, in Table 4.5.

4.6 Probability of fire occurrence

Whilst the fire data can provide information on the number of fires caused by each type of appliance, in order to quantify the relative likelihood of fire occurring (i.e. the probability of a fire) a measure of the number of appliances in use must also be taken into account.

In order to do this (for both London and for England) data obtained by the UK Office for National Statistics (ONS) – "percentage of households with durable goods by UK countries and regions, 2012 to 2014" has been used [ONS, 2015]. This data set provides estimates of the percentage of households in the UK (including England as a whole and for individual regions, including London) having different types of appliances (including fridge-freezer, dishwasher, washing machine and tumble dryer) from which the number of households with each type of appliance can be derived.

Table 4.7. Estimated annual probability of fire by, white goods appliance type, for residential dwellings in London.

Ignition Source	Fires[1]	Average No of fires Per year	% Households with appliance[2]	Households with appliance[2]	Probability of fire (per year)[3]
Dishwasher	206	41.2	41%	1,320,200	3.1×10^{-5}
Tumble Dryer	208	41.6	42%	1,352,400	3.1×10^{-5}
Washing Machine	387	77.4	97%	3,123,400	2.5×10^{-5}
Fridge-Freezer	230	46	97%	3,123,400	1.5×10^{-5}

[1]Based on DS-1: Appliance fires in residential dwellings in London, 2011-2015, where the cause was attributed to a fault in the appliance.
[2]Based upon data for London from ONS Family Spending 2015 – Table A48: Percentage of households with durable goods by UK countries and regions, 2012 to 2014.
[3]Estimate assumes one appliance per household.

Based upon the fire data available for London (DS-1), Table 4.7 gives the number of fires, the percentage and number of households, and the annual probability of fire, found for each type of appliance. Both fridge/freezers and washing machines are present in almost all households (97%) in London, whereas dishwashers (41%) and tumble dryers (42%) are present in less than half of all homes. As a consequence, the annual probability of a fire occurring (for London) is estimated to be highest for both dishwashers and tumble dryers (3.1×10^{-5} per year) and lowest for fridge/freezers (1.5×10^{-5} per year).

Table 4.8 provides a similar breakdown, for England (DS-2), of the number of fires, households, and the annual probability of fire for each type of appliance. As is the case for London, the level of ownership for fridge-freezers

(98%) and washing machines (97%) is almost universal, whilst being significantly lower for dishwashers (42%). However, a higher percentage of households in England (56%) are estimated to have tumble dryers than is the case in London. Hence, the annual probability of fire (for England) is estimated to be marginally higher for dishwashers (3.5 × 10^{-5} per year) than for tumble dryers (3.2 × 10^{-5} per year). Once again fridge/freezers exhibited the lowest probability of fire occurrence (1.1 × 10^{-5} per year).

Table 4.8. Estimated annual probability of fire by, white goods appliance type, for residential dwellings in England.

Ignition Source	Fires[1]	% Households with appliance[2]	Households with appliance[2]	Probability of fire (per year)
Dishwasher	1968	42%	9,361,800	3.5 × 10^{-5}
Tumble Dryer	2405	56%	12,482,400	3.2 × 10^{-5}
Washing Machine	2765	97%	21,621,300	2.1 × 10^{-5}
Fridge/Freezer	1403	98%	21,844,200	1.1 × 10^{-5}

[1]Based on DS-2: Appliance fires in residential dwellings in England, 2010/11-2015/16, where the cause was attributed to "faulty appliances and leads".
[2]Based upon data for England from ONS Family Spending 2015 – Table A48: Percentage of households with durable goods by UK countries and regions, 2012 to 2014.
[3]Estimate assumes one appliance per household.

The results can be seen to be reasonably consistent between London (Table 4.7) and England as a whole (Table 4.8), with broadly similar annual fire probability estimates (and ranking of the different appliance types) being obtained for each type of white goods appliance.

4.7 Fire risk

Table 4.9 summarises the estimated annual probability of a residential dwelling fire in London (DS-1) and the consequences of fire in terms of casualty rate per fire and the likelihood of fire spread beyond the room of origin for each of the appliance types. Having obtained estimates for probability of fire occurring and consequences of fire, the risk of fire can be quantified as:

$$\text{Fire risk} = \text{Probability of fire occurring} \times \text{Consequences of fire}$$

The risk of fire casualties per year and risk of fire spread beyond the room of origin per year for each of the appliance types are also given in Table 4.9.

Table 4.9. Estimated annual risk of fire casualties and fire spread beyond the room of origin, by white goods appliance type, for residential dwellings in London.

Ignition Source	Probability of fire (per year)	Casualty rate (per fire)	Probability of fire spread beyond Room of Origin (per fire)	Risk of fire casualty (per year)	Risk of fire spread beyond Room of Origin (per year)
Dishwasher	3.1×10^{-5}	0.223	0.08	7.0×10^{-6}	2.5×10^{-6}
Fridge-Freezer	1.5×10^{-5}	0.335	0.39	4.9×10^{-6}	5.7×10^{-6}
Tumble Dryer	3.1×10^{-5}	0.178	0.20	5.5×10^{-6}	6.2×10^{-6}
Washing Machine	2.5×10^{-5}	0.034	0.06	8.4×10^{-7}	1.5×10^{-6}

Based on DS-1: Appliance fires in residential dwellings in London, 2011-2015, where the cause was attributed to a fault in the appliance.

The results suggest that the overall risk of a fire casualty occurring is higher for dishwashers and tumble dryers than it is for fridge-freezers (despite fridge-freezers exhibiting the highest casualty rate per fire) due to their both having a higher probability of fire incidence. The risk of a fire casualty due to washing machine can also be seen to be significantly lower than is found for the other appliance types.

In terms of risk of fire spread beyond the room of origin (and consequently a high level of damage) tumble dryers display a slightly higher overall risk of fire damage than fridge-freezers (despite their having a higher probability of spreading beyond the room of origin) again because of their higher probability of fire occurrence. Conversely the risk of fire damage is lower for both dishwashers and washing machines.

Table 4.10 summarises the estimated annual probability of a fire, in England (DS-2), and the consequences of fire in terms of the proportion of incidents involving one or more casualties (note that DS-2 only indicates whether an incident involved casualties or not and does not specify how many casualties were involved) and the probability of fire damage size greater than 5 m^2 per year for each of the appliance types. The risk of a fire incident involving one or more casualties per year and risk of fire damage size greater than 5 m^2 per year for each of the appliance types, in England, are also shown.

Table 4.10. Estimated annual risk of one or more fire casualties and fire damage extent greater than 5m^2 by white goods appliance type, for residential dwellings in England.

Ignition Source	Probability of fire (per year)	Probability of at least one casualty (per fire)	Probability of fire damage extent > 5 m^2 (per fire)	Risk of one or more casualties (per year)	Risk of fire damage > 5 m^2 (per year)
Dishwasher	3.5×10^{-5}	0.11	0.20	3.9×10^{-6}	6.9×10^{-6}
Fridge-Freezer	1.1×10^{-5}	0.18	0.47	1.9×10^{-6}	5.1×10^{-6}
Tumble Dryer	3.2×10^{-5}	0.10	0.28	3.2×10^{-6}	8.9×10^{-6}
Washing Machine	2.1×10^{-5}	0.05	0.08	1.1×10^{-6}	1.7×10^{-6}

Based on DS-2: Appliance fires in residential dwellings in England, 2010/11-2015/16, where the cause was attributed to "faulty appliances and leads".

The results for England (DS-2) appear to be broadly consistent with those found for London (DS-1), suggesting that the overall risk of a fire in terms of both involving one or more casualties and being responsible for fire damage size greater than 5 m^2 is even higher for dishwashers and tumble dryers than it is for fridge/freezers (again because of their having a higher probability of a fire starting). However, the results also show that, should ignition occur, fridge/freezer fires (in the UK) are more likely to spread beyond the room of origin and be responsible for a greater level of damage (produce a larger fire damage area) than the other types of white goods appliance.

4.8 Time of appliance fires

Fig. 4.6 shows the number of fires observed (DS-1) for each type of appliance, by the hour of the day in which they occurred (when the call to the fire brigade was received). The results (although subject to a degree of fluctuation) suggest that fridge-freezer fires were reasonably evenly spread across the day and night reflecting their continuous operation. However, the other types of appliance fire appear to mirror patterns of human activity, with large numbers of washing machine fires occurring throughout the day and evening and the number of tumble dryer and dishwasher fires rising through the day and peaking in the early evening and around midnight respectively. In contrast to fridge-freezer fires, far fewer incidents involving the other types of appliance occurred during the early hours of the morning.

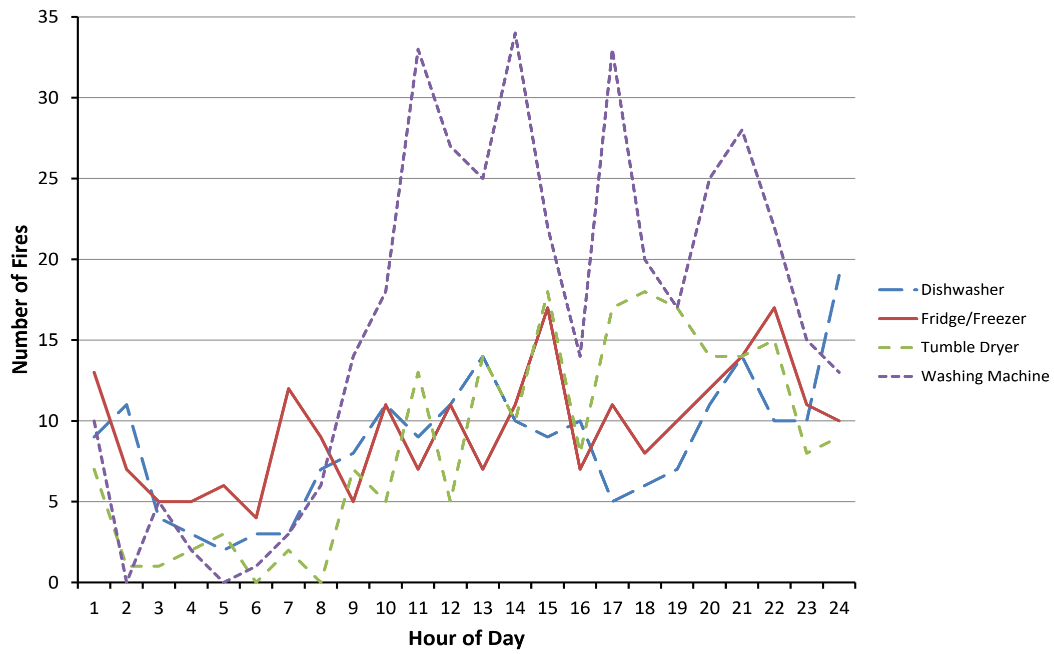


Figure 4.6 The number of fires observed in residential dwellings in London (DS-1) for each type of white goods appliance, by hour of day the complimentary cumulative distribution function (CCDF) for fire damage area (DS-2) that is obtained for each type of appliance (the CCDF gives the probability of a fire exceeding a particular fire damage area – see, for example, Fullwood and Hall (1988).

Fig. 4.7 provides a breakdown of the number of fire incidents (DS-1) by type of appliance and whether the incident occurred during the day (taken here to be 8 am to 8 pm) or at night (8 pm to 8 am). Whereas the number of fridge-freezer and dishwasher fires are fairly evenly divided between the day and night, washing machine and tumble dryer fires occurred predominantly during the day.

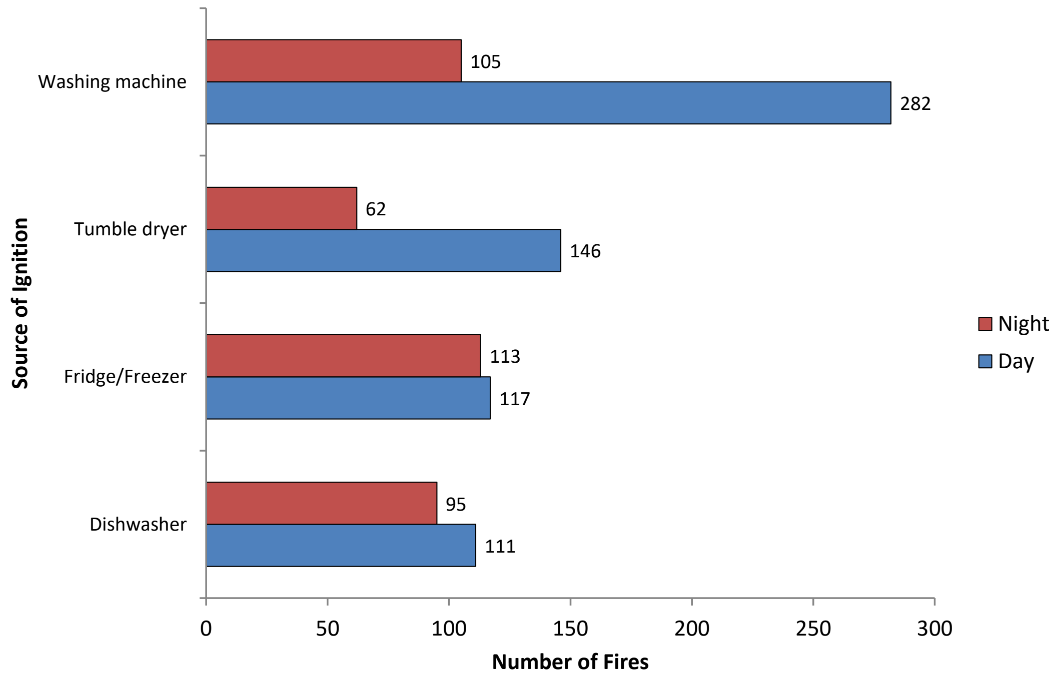


Figure 4.7 The number of fires observed in residential dwellings in London (DS-1) by type of white goods appliance and whether the incident occurred during the day or at night.

Fig. 4.8 provides a breakdown of the number of fires observed (DS-1) for each type of appliance, by month of year. The results suggest that there may be an increase in the number of fridge-freezer fires occurring during the summer months (particularly July and August) in comparison to the other months of the year. By comparison, the number of washing machine fires has two peaks – one during the spring and one during the autumn, with fewer fires occurring during the winter months – whilst the number of dishwasher fires appears relatively consistent across the year. The results also suggest that a lower number of tumble-dryer fires occurred in summer (August).

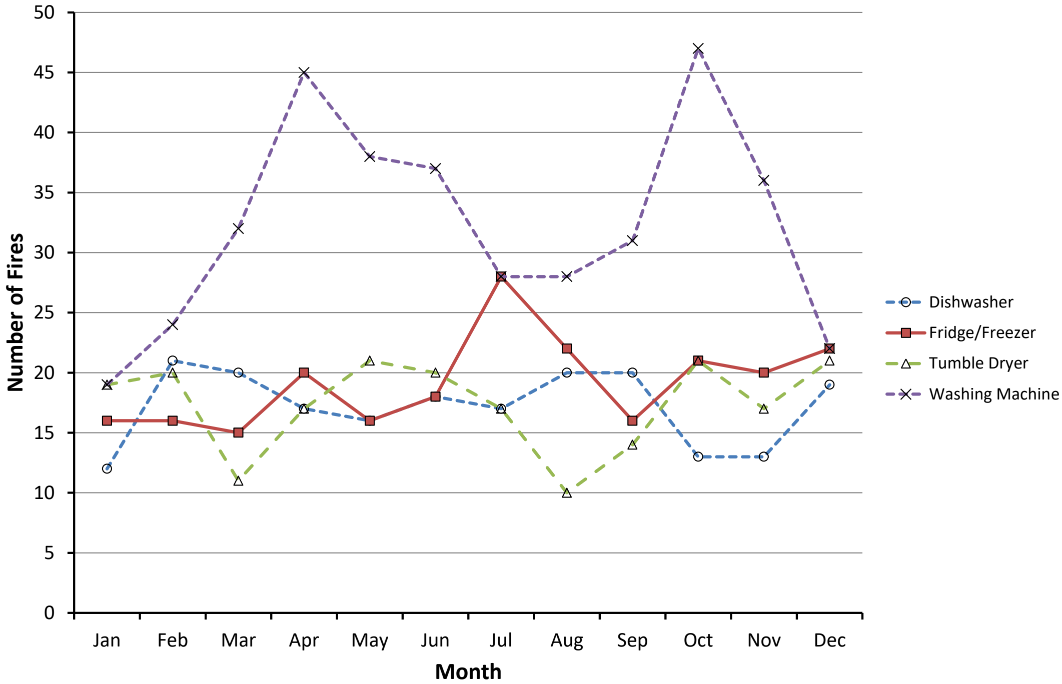


Figure 4.8 The number of fires observed in residential dwellings in London (DS-1) for each type of white goods appliance, by month of year over a 5-year period.

Table 4.11 Location of room of fire origin, by white goods appliance type, for residential dwellings in London.

Ignition Source	Room of Origin	Fires	% of Fires
Dishwasher	Kitchen	203	99%
	Utility room	3	1%
Fridge-Freezer	Kitchen	192	83%
	Utility room	7	3%
	Garage	7	3%
	External structure	7	3%
Tumble Dryer	Kitchen	116	56%
	Utility room	44	21%
	Garage	8	4%
	Conservatory	7	3%
Washing Machine	Kitchen	331	86%
	Utility room	30	8%

Based on DS-1: Appliance fires in residential dwellings in London, 2011-2015, where the cause was attributed to a fault in the appliance.

4.9 Location of the fire

Table 4.11 provides a breakdown of fire data (DS-1), for the different types of white goods appliance, by the room in which the fire originated. As might be expected, the majority of the fires - 99% of the dishwasher fires, 86% of the washing machine fires and 83% of the fridge/freezer fires - started in the kitchen. By contrast, only just over half (56%) of the fires involving tumble dryers started in the kitchen, with a high percentage of these fires (21%) also originating in a utility room.

4.10 Summary

An analysis of fire data for white goods appliances in residential dwellings in the UK (England and London) has been carried out. The results suggest that, once ignition occurs, fires caused by fridge-freezers are more likely to exhibit a higher degree of fire spread and produce greater levels of damage than other types of white goods appliance (washing machine, dishwasher or tumble dryer). Nearly 80% of fires with fridge/freezers as the source of ignition, spread (caused fire damage) beyond the first item involved, whilst almost 40% spread beyond the room of origin (usually the kitchen). Fires involving fridge-freezers also displayed a far higher casualty rate per fire (340 casualties per 1000 fires) than was found for the other types of appliance. However, the results also indicate that fridge-freezers have a lower probability of a fire occurrence than the other types of white goods appliance, and that consequently both tumble dryers and dishwashers present an even greater overall fire risk than fridge-freezers.

Chapter 5

Common Failure Modes Leading to Ignition

5.1 Introduction to Chapter

Based upon an analysis of LFB fire investigations of a large number ofincidents using the procedure outlined in Chapter 3, the following failure modes leading to ignition in domestic refrigeration fires have been identified:

i. Starter relay failures
ii. Possitive temperature coeficient (PTC) starter switch failures
iii. Mechanical defrost timer switch failures
iv. Capacitor failures
v. Cut-out switch failures in integrated appliances
vi. Solenoid valve failures
vii. Rodents

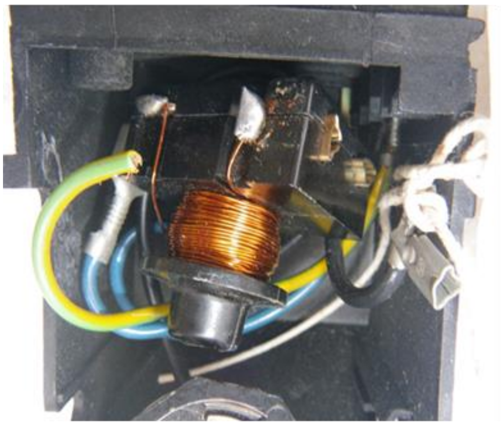
In this Chapter, each of the failure modes will now be examined in more detail.

5.2 Starter relay failures

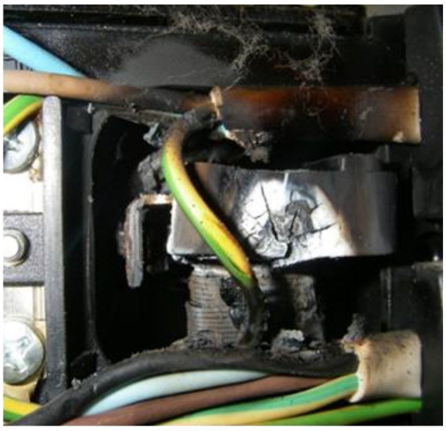
Probably the most popular model of domestic refrigeration used throughout Europe is the fridge-freezer. Some of the more expensive models have a compressor for each compartment, but in general a single compressor provides cooling for both the fridge and freezer units.

Earlier models of fridge-freezer employ a starter relay that is attached to the compressor – see Figure 5.1(a). This allows current to pass to the starter windings of the compressor. Once the compressor starts to run, the relay opens, cutting off the current, and the compressor then functions independently.

Figure 5.1(b) shows an example of a typical starter relay failure, resulting in severe heating to the coil assembly and external heat damage to adjoining cabling. The centre area, seen with white pyrolyzed plastic, has broken up following an attempt to remove it (Figure 5.1(c)). This particular failure produced a small amount of smoke and an ‘electrical burning’ smell.



(a)



(b)

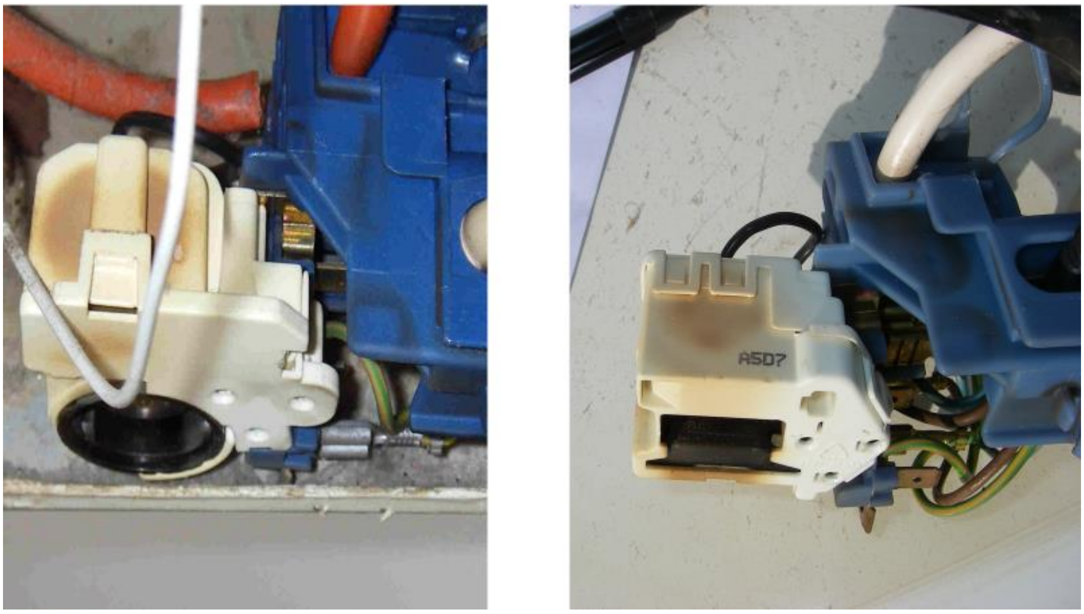
(c)

Figure 5.1 (a) An undamaged starter relay(Amenity site visit 10/2005 Ref no 6) (b) an example of a typical starter relay failure – note the white pyrolyzed plastic region; (c) break-up of the pyrolyzed plastic region upon removal. (b) and (c) Ref LFB Fire incident 04/2007

This failure mechanism has been observed for many years. However, the shift by manufacturers to using PTC starter switch’s, together with the often-limited amount of resulting damage, has meant that the number of incidents caused by starter relays has become less common and is now in decline.

5.3 Positive Temperature Coefficient (PTC) starter switch failures

The starter switch (used to start the operation of the compressor by allowing an electrical current to flow) normally consists of a PTC ‘pill’ or disk, housed in a plastic body containing the electrical connections. The pill is normally a coin sized circular unit constructed of compressed, barium titanate ceramic powder, in its pure form this is actually an electrical insulator. However, when doped with small amounts of metals, it becomes a semiconductor. Both side facings of the pill are coated in a ‘silver’ conductive coating which provides electrical conduction. The pill functions as a conductor until it reaches a critical temperature (around 120°C) above which it becomes a resistor (with the resistance increasing very steeply). Hence the pill effectively functions as a temperature switch. The switch body sometimes also contains a compressor overload switch.



(a) (b)

Figure 5.2 Examples of heat deformation to PTC switch casings

The switch continues to operate whilst the fire resistance of the plastic casing slowly degrades. (a) Amenity site 11/2006 Ref PTC no 61) (b) Amenity site 10/2006 Ref PTC no 322)

(a) (b)

Figure 5.3 Two examples of partially fractured and damaged PTC switch's showing evidence of flaking and shelling around the edge of the pill: (a) Amenity site visit 01/2006 Ref PTC no 144. Material breakage from pill edge and heat patterns to pill contact face. Rusting to connector plate suggests water ingress to switch. (b) Amenity site 08/2006 Ref PTC no 272. Damage to pill edge and heat pattern to inside of top cover.

In late 1999 LFB were contacted by the Swedish Rescues Services Agency and made aware of a report of 162 fires involving refrigerators, many of which had been determined as being caused by the compressor PTC starter switch. The switches were all produced by the same manufacturer, but often appeared in different models of appliance. In appearance, the defective PTC pill exhibited tracking across its edge. There was also often evidence of flaking or 'shelling', breaking around the edge of the pill (see Figure 5.3 b). This pattern of damage seems to be much less prevalent in newer now of a generally smaller diameter and often a much thinner design. Older pills had silvering to the pill edges (see Figure 5.3(a)). In the construction of later (and current) switch's, there is an un-silvered gap left at the edge.

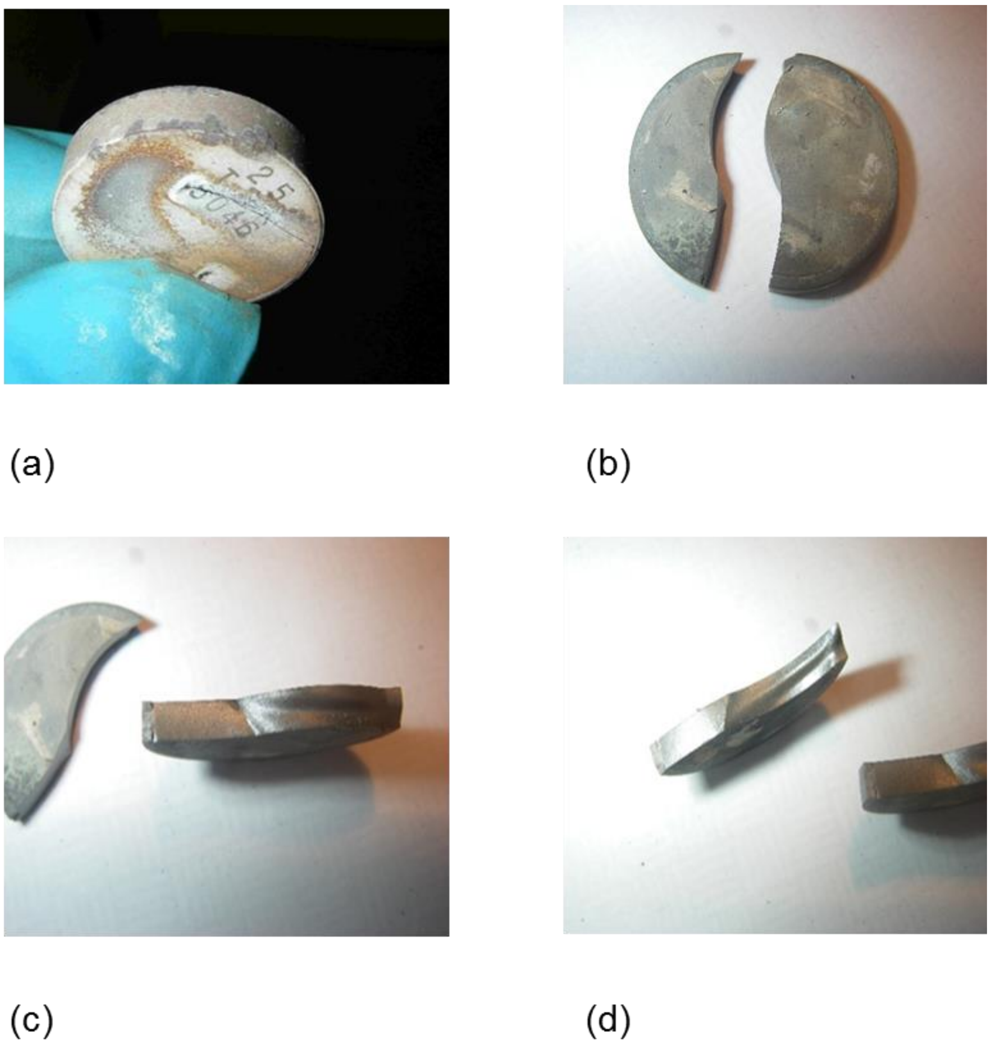


Figure 5.4 Damage exhibited by PTC pills: Figure (a) is an early pill design and shows the effect of edge damage associated with silver migration. Figures (b-d) show the more modern, thinner, pill with breakage consistent with an electrical rather than a mechanical failure.

In Figure 5.5 the resistance versus temperature graph shows how a PTC pill reacts to temperature changes. Tb = transition temperature Is the temperature where the ceramic microstructure changes. The resistance above this point is much higher than the resistance below this point.

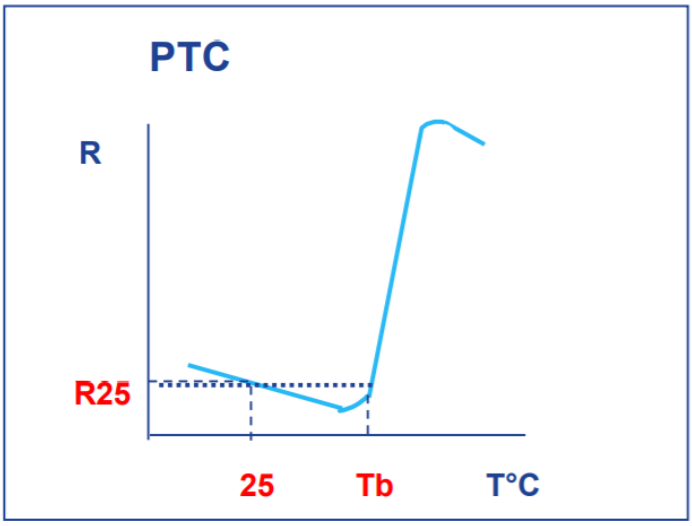


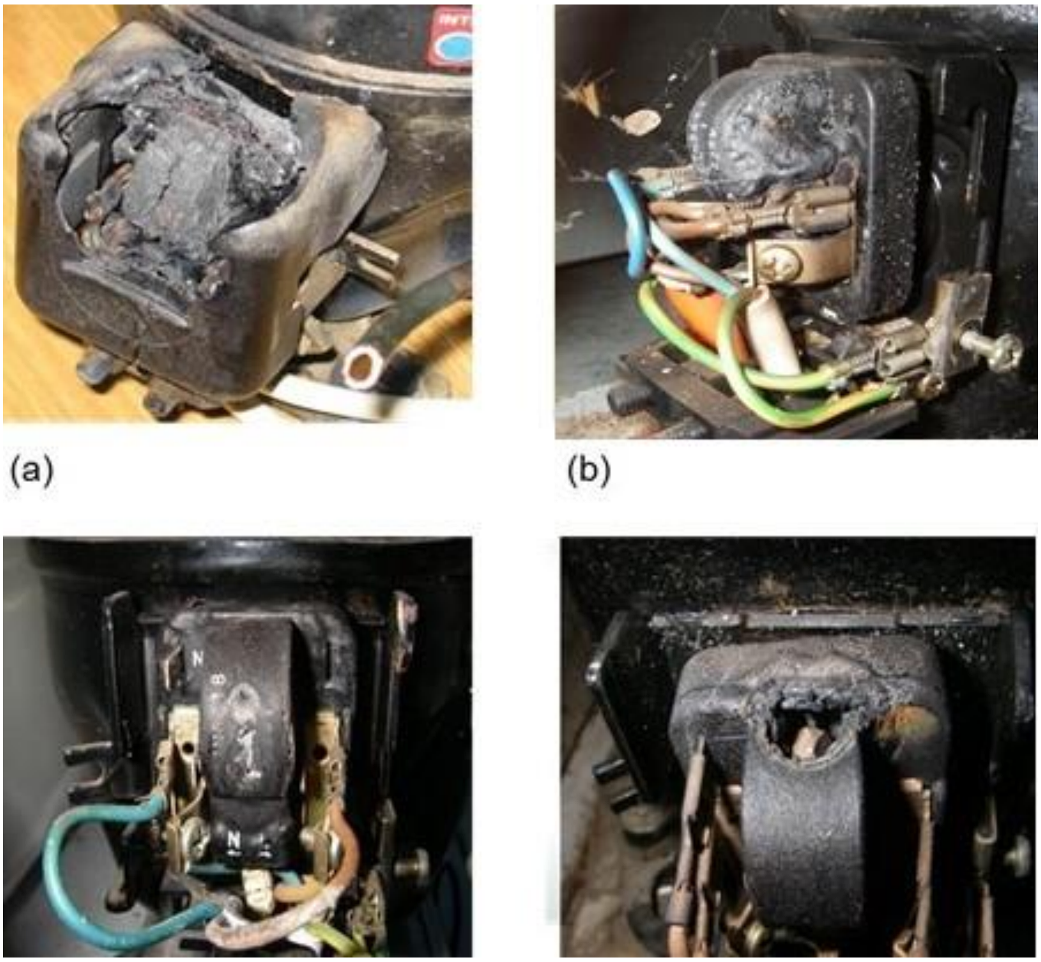
Figure 5.5 Resistance versus temperature chart for a PTC pill

Degrading appears to continue with the pill eventually Fracturing. The casing of the switch is typically distorted and will degrade and often split. Arcing can be observed as the pill is sufficient to melt the metal contacts within the switch. There is a plastic cover over the top of the switch which may slowly degrade, almost being baked. The cover may also exhibit signs of burning. It is possible that ignitable gasses can collect inside the switch cover and may ignite from arcing from the switch contacts with the pill. A fractured pill can often be found in many pieces, but will still function, providing a contact is maintained.

A research paper by Kim et al. (1996) “Electrical breakdown of positive temperature coefficient of resistivity barium titanate ceramics”, details the failures often caused by this dielectric breakdown. It describes the grain sizes of the pill and examines differing sizes and qualities of pill construction, highlighting the difference in the way that a mechanical (jagged edged break) versus electrical break (smooth edges) will appear. An electric current passing through the pill from one silvered side to the other, will take the path of least resistance. Even when the pill has broken into many pieces, a path may still be possible, producing arcing and melting of the metal conductors.

Such was the concern for these common switch failures that LFB approached appliance producers and manufacturers, but they claimed to have no knowledge of this failure mechanism. LFB eventually met with the compressor manufacturers who confirmed that the composition of the switch construction had been changed in 1994. They were aware of a ‘selected’ number of incidents that had occurred in ‘summer houses and country cottages’. They also suggested that ignition seemed to be more prevalent following re-energising of an appliance following switch off. The research does show that ignition has occurred on several occasions following a major defrost of an appliance, followed by its re-energising.

Figure 5.6 shows a selection of Danfoss PTC starter switch’s displaying differing levels of decomposition. The heat generated from the current passing through the PTC pill slowly bakes the plastic covering. Inside the switch, crystals of Adipic acid form, which provide a constant electrical path across the side of the ceramic PTC pill. The resulting heat begins a pyrolyzing process. The plastic covering of the PTC pill switch expands leaving the switch with a swollen casing, which typically cracks open. Figure 5.6(a) shows the outer cover, partially pyrolyzed and burnt, exposing the switch beneath. Figure 5.6(b) shows a severely swollen ptc cover, a common stage in the switch’s degradation. Figure 5.6(c) shows another switch with a later compressor mounting cradle, but still utilising the same switch design. The pyrolysis process in this case is at an earlier stage. Finally, figure 5.6(d) shows a hole burnt in the case and pyrolyzing/burning through the switch plastic, (notice the char layer around the edge of the hole exposing a piece of PTC pill within. Although the pill had fractured, the switch was still functional and able to pass a start current to the compressor. This freezer appliance was kept at New Cross FIU and was filmed, with the starter switch still functioning.



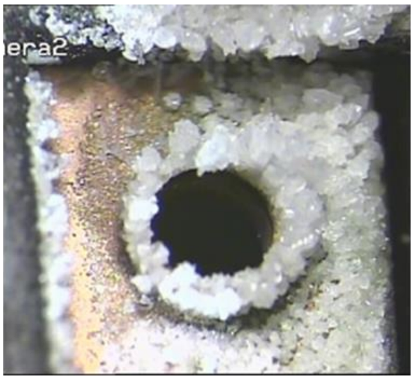
(a) (b) (c) (d)

Figure 5.6 Examples of thermal decomposition in failed PTC. switch's (a) Bureau Veritas sample. (b) LFB Fire incident no 84294101 05/2010. (c) LFB Fire incident no 143805131 02/2013. (d) Amenity site visit 11/2006 Ref PTC no 324.

The white crystalline material which develops on the surface of the switches is adipic acid produced by a reaction involving nylon present in the switch's casing material. A build-up of adipic acid was often found to be present inside the switch cover prior to or following the failure of the switch (Figure 5.7).

Figure 5.7 Build-up of adipic acid inside the cover of a PTC switch.

The manufacturers later confirmed that the addition of nylon within the make-up of the covering had been changed and they were confident that no similar failure would occur in the modified switches.



(a)

(b)

(c)

(d)

Figure 5.8 Some examples of adipic acid found on PTC switches.

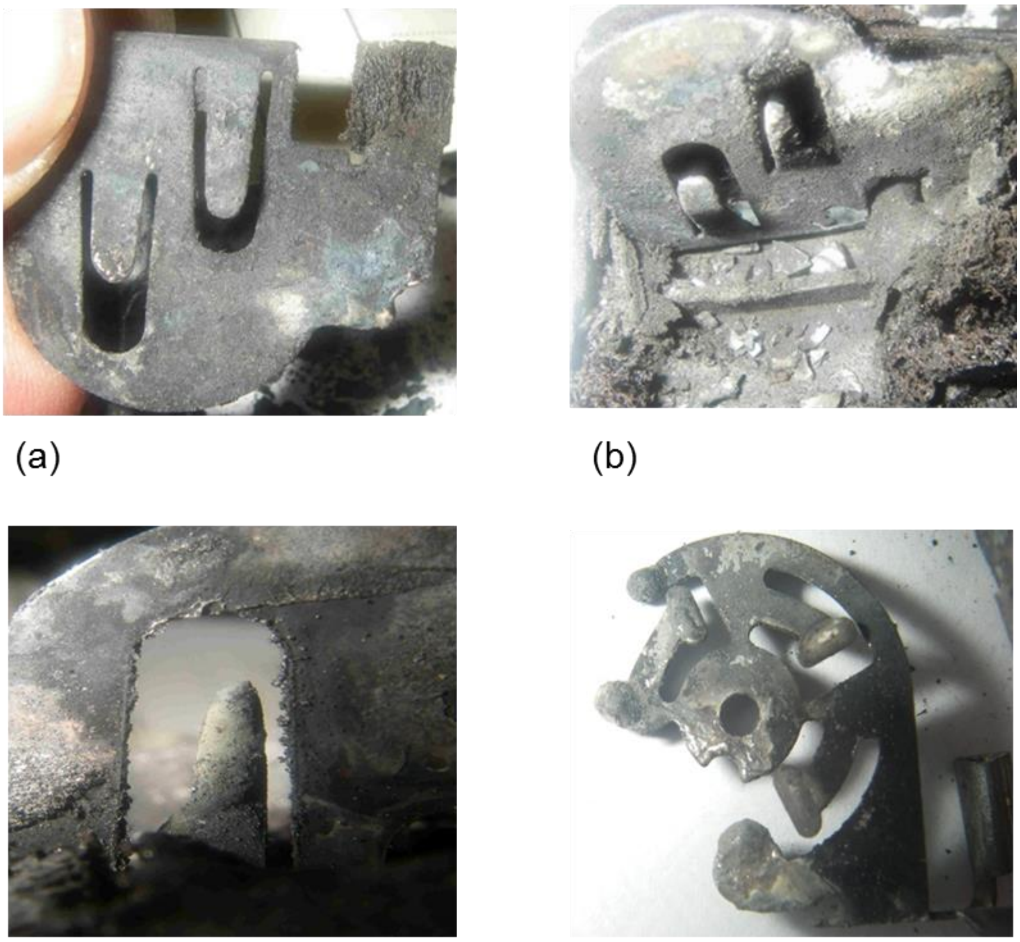
Figure 5.8(a-b) shows example of adipic acid found on switch surfaces viewed under a microscope. The acid also appears to damage the ceramic edge (see Figure 5.8(c-d)) creating a potential arc path across the pill.

All designs of PTC switch are constructed with metal contact plates (Fig 5.9) which provide an electrical path between the compressor and the PTC pill or disk. The sprung contacts may be noticeably damaged by arcing if the pill has broken. Even when the pill is found severely fragmented, the switch will continue to operate provided contact is maintained.

(a) (b)

Figure 5.9 Examples of localised heat damage and arcing to metal contacts within PTC switches. ((a) Amenity site visit 01/2006 Ref PTC no 134) ((b) Amenity site visit 05/2006 Ref PTC no 306)

Figure 5.9(a) shows a side contact plate which is normally a light brass colour. Heat from the contact with the PTC pill produces the almost white coloured circle. Figure 5.9(b) shows the result of arcing from the PTC pill to the sprung metal contacts, resulting in distortion and melting of the metal plate. These switch plates will survive the severest domestic house fire, providing evidence of long-term arcing and failure of the switch. Figure 5.10 shows some further examples of PTC switch contact electrical damage to the sprung contact arms.



(a) (b) (c) (d)

Figure 5.10 Some examples of PTC switch contact electrical damage to sprung contact arms. ((a) (b) (c) Amenity site visit 09/2006 Ref PTC switch no 289) ((d) LFB Fire incident no 707280351 04/2008) An energised switch, damaged as a result of a fire spread from another ignition source would not produce arcing/ failure of contacts in this way.

The starter switch continues to have a potential for failure and is normally always examined, even if only for exclusion purposes. Although failures may be common in models other than those manufactured by Danfoss, experience suggests that such failures have not often led to a fire occurring.

5.4 Mechanical defrost timer switch failures

From around 2004 onwards, it became apparent that a number of fires involving fridge-freezers were taking place that did not appear to follow the pattern of the failure modes that had been identified up to that point in time. The appliances appeared to be of modern design and age. These fires were often serious, resulting in substantial property damage and casualties. They were almost always severe enough to destroy a large proportion of the appliance, resulting in damage to several components, and all of the potential ignition sources. Part of the research project involved regular visits to local authority re-cycling yards where permission had been given to examine refrigeration appliances (see Chapter 3). A number of defrost switches has been examined, but no evidence of a specific failure mechanism had been identified. Representation and consultation with the manufacturers was made and although the failure pattern had been recognised, no explanation as to the underlying cause could be identified.

However, in August of 2009, during a visit to the Council Amenity depot at Lewisham, examination of one particular model of frost-free fridge-freezer unit that had been discarded, suggested a potential failure mode scenario involving the defrost switch, that could explain what was happening (Figure 5.11). The defrost switch was mounted externally at the rear of the appliance. It was observed that the drain tube running from the refrigerator to the evaporation tray had become detached at its top joint. The defrost timer housing has a small adjusting hole near its base for manually setting/adjusting the timer (see inset in Figure 5.11). This hole had dirt and a discoloured liquid path showing. Although this type of switch was in general use by other manufacturers, no evidence of similar failures had been identified.

Upon removal of the defrost cover from its mounting, rust deposits were observed around the screw holes (Figure 5.11(a)). A piece of foam had been inserted into the hole through which the defrost wiring enters the fridge above (Figure 5.11(b)). Water staining to this foam, matching the metal covering plate, indicated that water had entered the switch from above (Figure 5.11(c)). There was also evidence of water staining/rust around the hole. (Figure 5.11(d)).

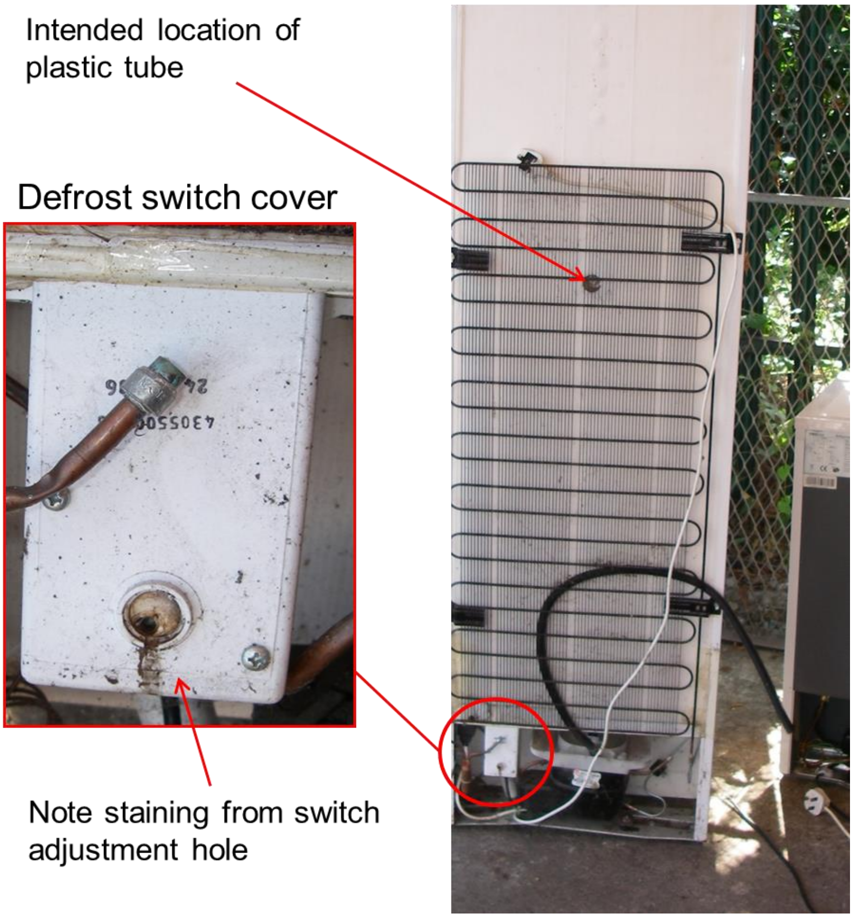


Figure 5.11 The rear of fridge-freezer. A magnified view of the defrost switch cover is also shown (inset). Note that the black plastic drain tube has come away from its original mounted position.

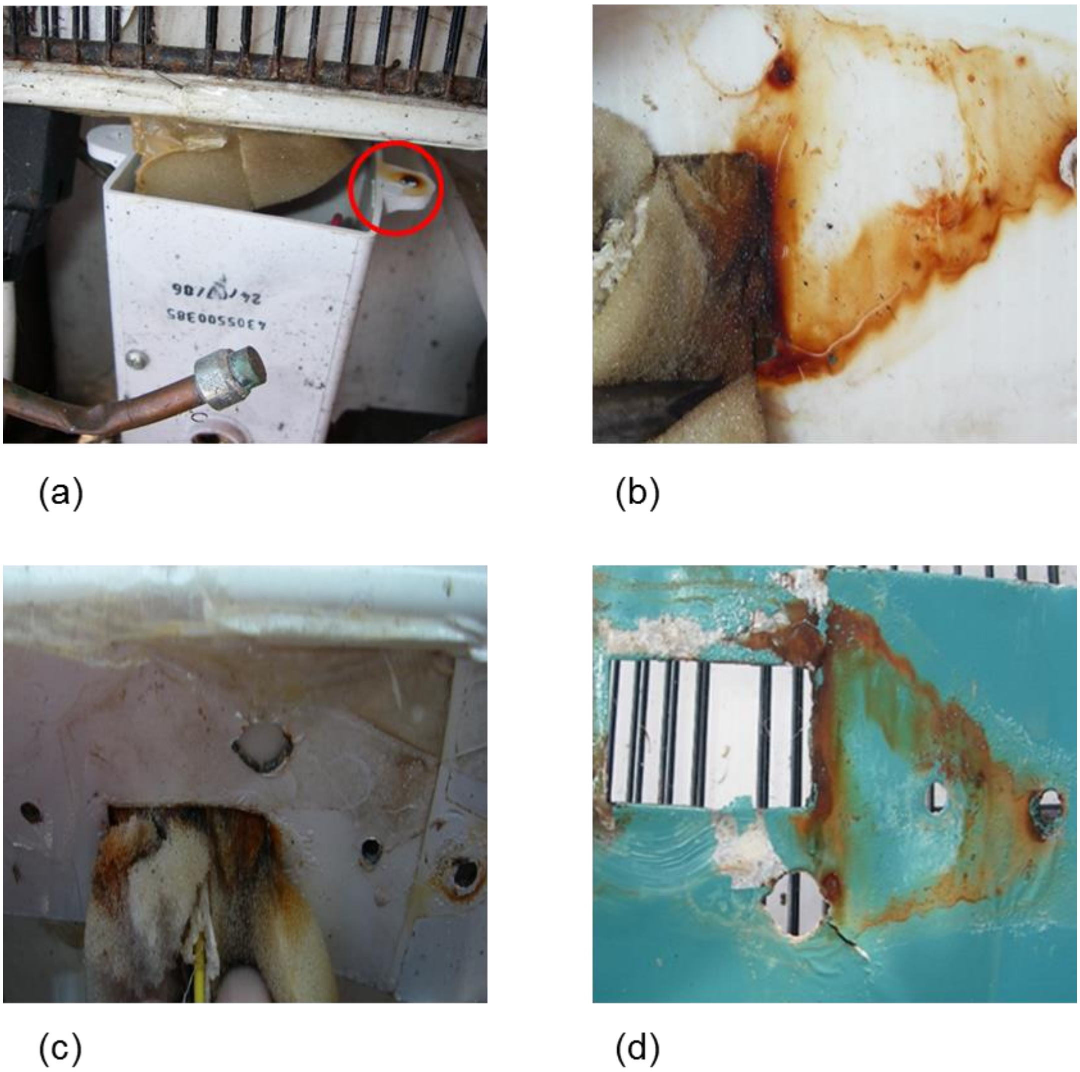


Figure 5.12 (a) Evidence of rust deposits around the screw holes; (b) foam pushed into the defrost switch wiring hole; (c) water staining to the foam matching the metal covering plate indicating that water entered the switch from above; (d) further evidence of water/rust staining around the hole.

The defrost timer switch was subsequently x-rayed prior to being dismantled. A second undamaged switch was also x-rayed and used a reference for comparison. Figure 5.13 shows the two x-ray images that were obtained, with the undamaged switch shown on the left and the damaged switch on the right.

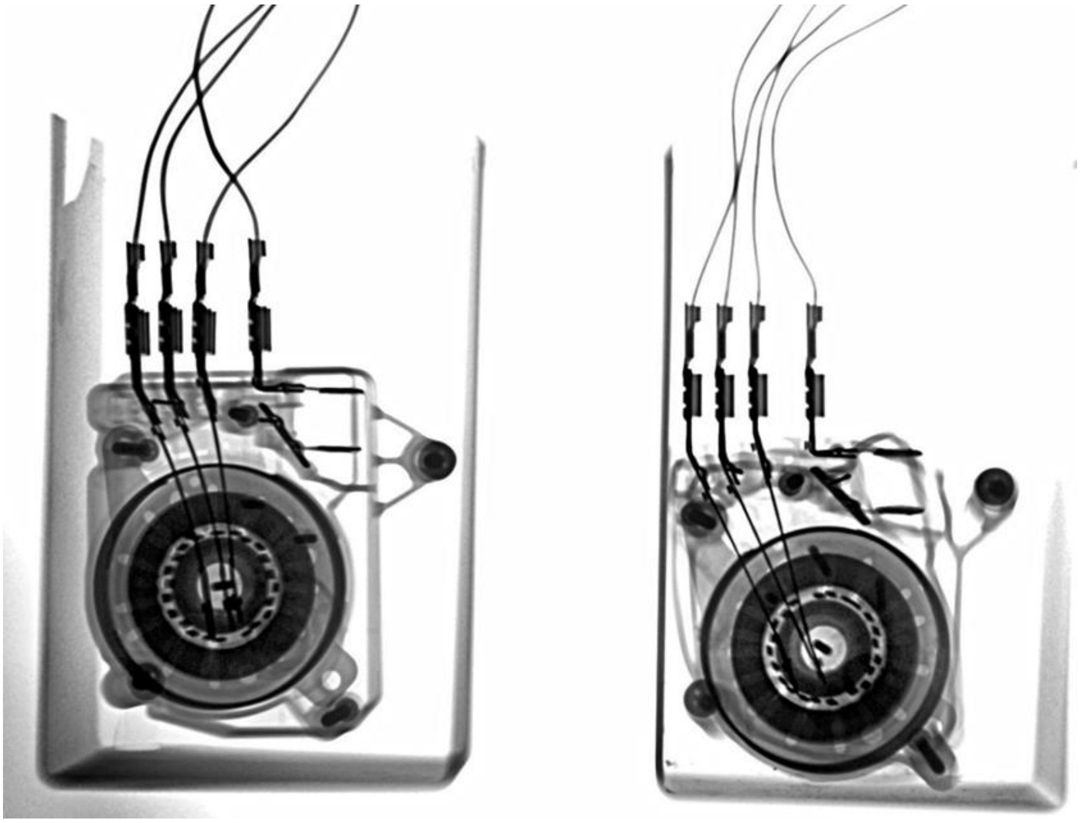
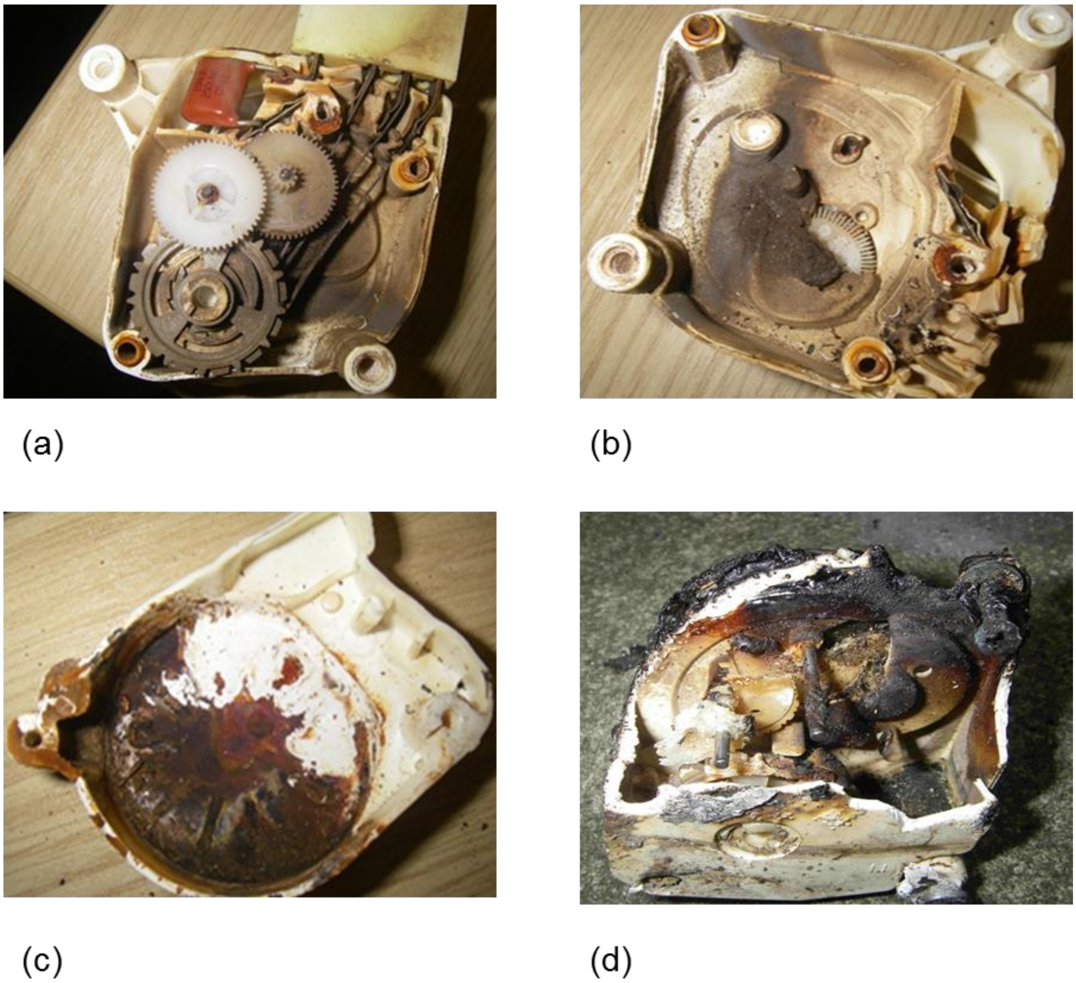


Figure 5.13 A comparison of the x-ray images obtained for the undamaged (left) and damaged (right) defrost timer switches. The left unit shows a normal contact between two of the connecting contact arms. The right-hand unit shows distortion of the plastic frame by heat and two of the contact arms electrically fused together.

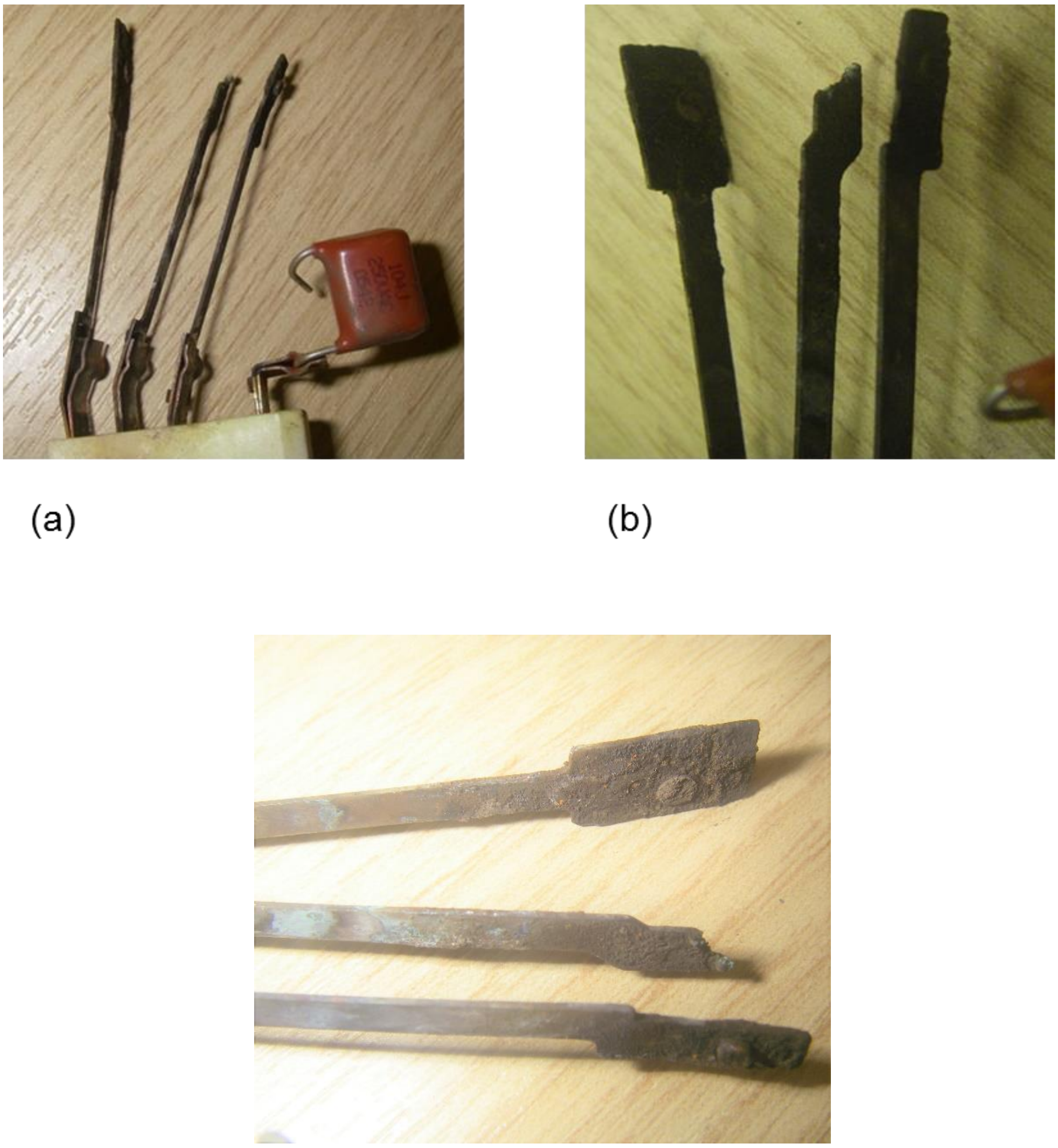
The switch was then dismantled and compared with the undamaged switch (Figure 5.14(a)) to reveal melting and distortion of the plastic casing by the effect of heating and evidence of water penetration into the switch (Figure 5.14(b-d)). There was also evidence that severe arcing had occurred to the switch contacts (Figure 5.15).

The external switch cover is constructed of fire resisting plastic, but the cogs within the switch have a high nylon content and will burn readily. Because the inside of the switch is effectively a sealed compartment, combustion in the interior of the switch will initially be limited. However, once the cover has distorted and started to melt, the internal components will be exposed to the atmosphere and the switch components will be able to burn and spread the fire to the switch cover (and then to the appliance insulation).



(a) (b) (c) (d)

Figure 5.14 Dismantled defrost timer: switch's (a) the undamaged switch; (b-d) the heat damaged switch, revealing evidence of melting of the plastic casing and water ingress within the switch and timer.



(a) (b) (c)

Figure 5.15 (a) Contacts within the damaged switch; (b) close-up revealing evidence of severe arcing. (c) close up of contact switch remains.

A sampled defrost switch removed from the external covering was then tested to show its burning/flaming characteristics (Figure 5.16). A defrost switch was secured by a clamp and a small blow lamp flame was introduced to the external surface of the cover. The test showed free burning to the switch occurred once the internal plastics were introduced to a flame.

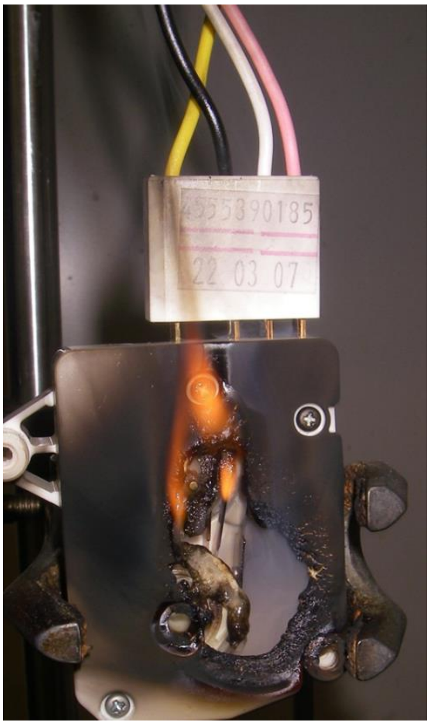


Figure 5.16 A test performed on a sample defrost switch, illustrating the significant flaming behaviour produced. (Bureau Veritas Lab tests 2013)

The fire retarded cover would not sustain a free burning flame. As the cover melted it exposed the components of the timer. The plastic wheels within the timer were made of hard-wearing nylon-based plastic and burned easily, continuing to burn even when the flame from the torch was removed.

This process of ignition and burning of the defrost switch means that in almost all cases, the fire will spread rapidly to the insulation producing an intense fire (see Chapter 6). This process of destruction of the switch, and particularly its external casing, typically leaves little for the investigator to examine. Figure 5.17(a) shows a rare event where the fire was discovered quickly and extinguished before the fire could develop and spread to the insulation above. In this case, the switch was then removed to reveal water staining in the base of the switch cover (Figure 5.17(b)). Water ingress into the switch appears to provide an explanation for the cause of this failure.

(a) (b)

Figure 5.17 (a) An example of a rare case where a fire in a defrost switch was discovered and extinguished before the switch was destroyed; (b) evidence of water staining under the base of the switch cover. (LFB incident no 79992081 05/2008).

Figure 5.18 shows a typical fire damaged appliance which was recorded as a defrost switch failure. The severe damage within the compressor area involves all the electrical components, making a defined cause difficult to positively identify without examining and discounting the capacitor, switch connections and PTC switch together with the mains cable and any other potential external ignition sources in the area

Figure 5.18 An example of a fire damaged appliance which was recorded as a defrost switch failure, illustrating the severity of the damage caused. (LFB Fire incident no 137039131 10/2013)

Over the period of this research a substantial number of switch’s have been examined. Whilst accepting that any switch contacts have the potential to produce an arc, the severe damage seen here (Figure 5.19) has only been seen in fire damaged examples and in most cases the presence of water staining was also observed.

Figure 5.19 An example of the severe arc damage caused to switch contacts.

The manufacturer was unwilling or unable to provide an explanation for the water ingress into the defrost switch. However, they were prepared to move the position of the switch to a new location on new models, further back above the compressor compartment away from possible water ingress, suggesting that it was as much the location of the switch as its failure that was the contributing to the severity of the problem.

Observations from examining numerous switch's suggested that the cover was fitted securely and that water could only enter the switch from above. The construction of the 'twin wall' plastic covering to the back of the appliance (see Chapter 6) is applied in a single piece, which fits from the top of the appliance down the rear and under the compression cavity then passing beneath the floor base finishing at the front of the machine. The two sheets of material have an air barrier between the layers and resemble a series of vertical straws. In Nov 2011, a sample appliance was examined at Bureau Veritas laboratory and tested to replicate the ingress of water/moisture. (Fig 5.18 to Fig 5.20)

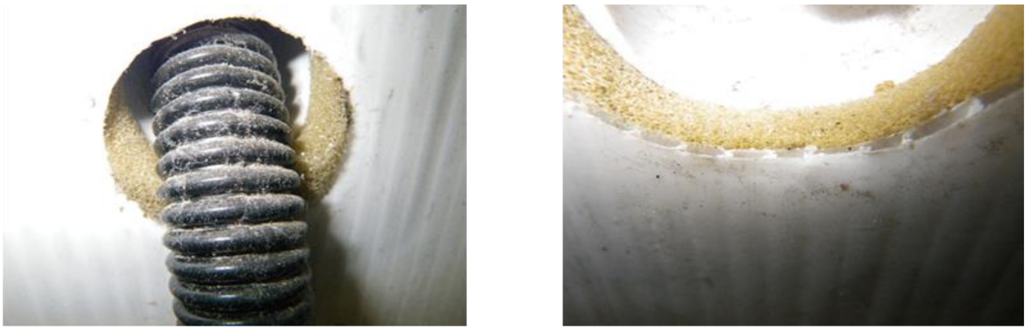
Figure 5.20 (a) illustrates the drain hole tube from the rear of the refrigerator section joins to the plastic outlet pipe. It is a push fit connection (Figure

5.20(a)). Although held in position by the rear condenser frame, (removed in photo) any disturbance to the drain hole, especially by attempting to poke something down the drain hole (as directed by some manufacturers - see Figure 5.20(b)) may well push the connection apart.

(a) (b)

Figure 5.20 (a) and (b) **shows** drain pipe to rear of appliance and internal drain hole (b).

Close up of hole in Figure 5.21 (a) and (b) shows construction of twin wall backing and foam insulating material behind it.

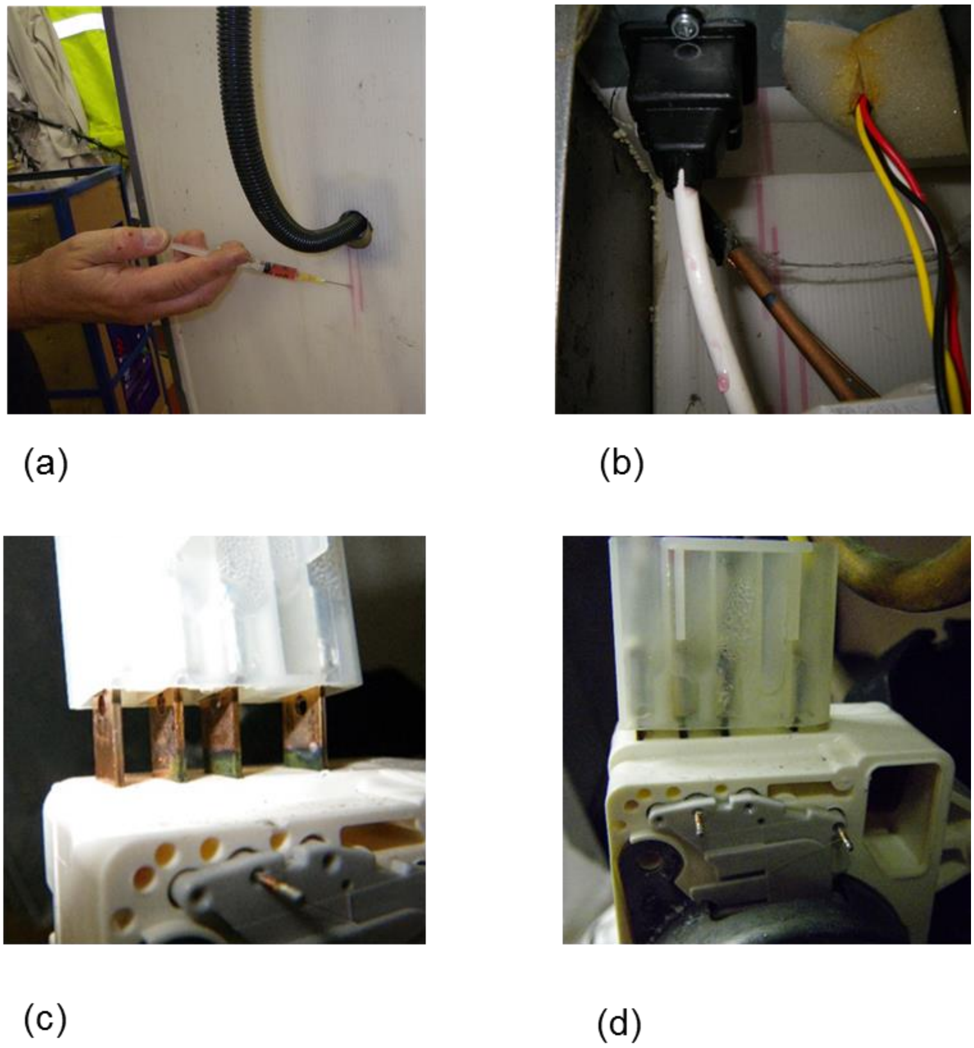


(a) (b)

Figure 5.21 Plastic drain pipe (a). Twin-wall backing (b) foam insulation and drain hole.

With the plastic drain pipe detached, the sponge gasket will soak up water. It was theorised that the some of this liquid might also flow across the twin walled plastic fridge backing material, (Figure 5.21(b)) and pass down the backing, trapped between the two layers, where it could then flow into the defrost timer switch via the mounting screw holes.

To test this theory, coloured liquid was injected into the cavity of the twin wall of a model that had the auto defrost switch factory fitted (Figure 5.22 (a)). The liquid ran down the tubes to the base. From here it was discovered that it could seep through penetrations in the sheet formed by the screws used to secure the main wiring harness and the defrost switch cover (Figure 5.22 (b)) and then run into the defrost switch by following the path of the wiring and flowing down to the connecting block. Figure 5.22 (c) shows the liquid has entered the plastic connecting block and started to heat up as a result of providing an electrical connection across the contact arms. This action also discoloured the base of the connecting copper contacts. Figure 5.22 (d) shows the liquid bubbling inside the plastic connecting block. This action did not result in a blown fuse or circuit failure. Hence it was concluded that this mechanism could explain how water was able to penetrate into the defrost timer switch.



(a) (b) (c) (d)

Figure 5.22 Testing the mechanism of water ingress into the defrost timer: (a) injection of coloured water into the fridge backing; (b) seeping through twin wall cavity following the wiring harness to the defrost timer; (c) water reaches the switch connecting block; (d) water forms a path across the switch contacts.

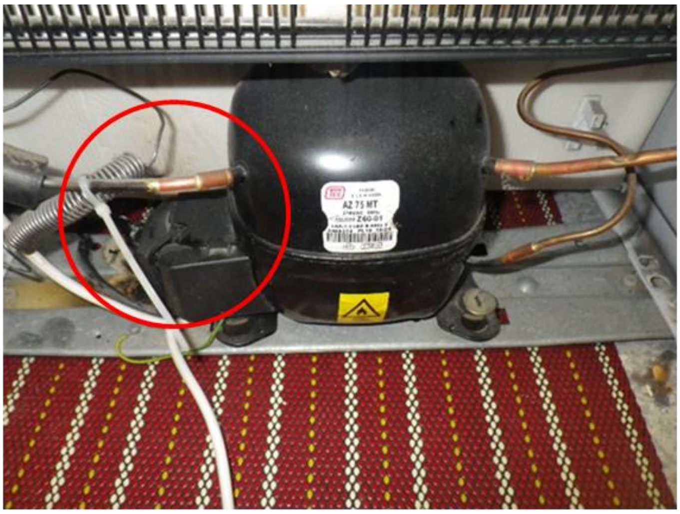
This type of defrost switch has been in use for many years and is fitted in many other appliances. The specific problem of this failure has not been reported by other manufacturers, although ingress of water may be deemed a problem in other circumstances. For example, PTC switches can also fail due to water ingress. Many appliance manufacturers have now switched to using electronic timers as was the case with this particular manufacturer.

5.5 Capacitor failures

The identification of appliance fires involving capacitors has become more common over recent years. It was the focus and research into defrost timer fires (see section 5.4) that originally provided evidence of this type of failure mode. Positioned within the same lower section of refrigeration appliances, its function is normally to smooth out electrical supply imbalances to the compressor at start-up or during operation. It is almost always located to the left of the compressor, but may also be found mounted adjacent to the compressor start switch. Its typical position, almost touching the insulating material, means that failure of this component invariably leads to fire spread to the refrigeration insulation producing an almost identical fire spread scenario to the defrost timer or PTC switch. In a well-developed fire it is almost certain that all three items will be severely damaged. As the capacitor often contains the least amount of potentially surviving material, the plastic casing is usually burnt away.

The lifetime of a component like a capacitor will generally vary according to the working conditions to which it is subjected and to its intrinsic properties. In service the capacitor is submitted to several types of stresses: over voltages, overheating, pollution, humidity, radiation and vibrations. Its life expectancy seems to be similar lifetime to that of a light bulb. Its failure can range from a simple fault of its circuitry, causing it to slowly melt and degrade through to char, to a dramatic and violent ignition or pressured eruption. Capacitors have been fitted to almost all modern refrigeration appliances since around the year 2000. Generally, the only exceptions are smaller units and ammonia evaporation cycle appliances.

Figure 5.23(a) shows an example of a capacitor failure within the compressor compartment of a freezer, which was approximately 9 years old. (LFB Fire Incident no 155184111 03/2013). Such a failure resulting in only limited fire damage is rare. It would also seem likely that this type of (limited) failure may go unrecorded in some cases as there is a possibility that no call to the fire brigade would be made.



(a)

(b)

(c)

Figure 5.23 (a) (b) and (c). Capacitor failure resulted in limited damage to the appliance.

Another example of a capacitor failure in a fridge/freezer appliance resulting in only localised damage. Fig 5.24, (a), (b) and (c) (Amenity site visit **06/**2009) shows the capacitor prior to removal from the compressor housing, and the capacitor and defrost switch following removal from the appliance.

.

(a)

(b)

(c)

Figure 5.24 Capacitor failure in a fridge/freezer appliance resulting in only localised damage to capacitor. (Amenity site visit 06/2009) (a) shows the capacitor prior to removal from the compressor housing. (b) shows the capacitor and defrost switch following removal from the appliance. (c) shows a close up of the burning within the capacitor casing.

Figure 5.25 (a) and (b) shows a further example of a failed capacitor. The sidewall on one side of the capacitor has partially melted exposing the remains of the internal components. The resulting failure did not result in a fuse or circuit breaker operation. In this case the component was still functioning when the occupier noticed a burning smell. (LFB Fire incident no 59981111 04/2011) The Brigade were called to a smell of burning within a kitchen. When the Investigator arrived, the refrigerator was moved away from its wall location and a small, intermittent glow was observed within the capacitor. The appliance was removed for analysis.

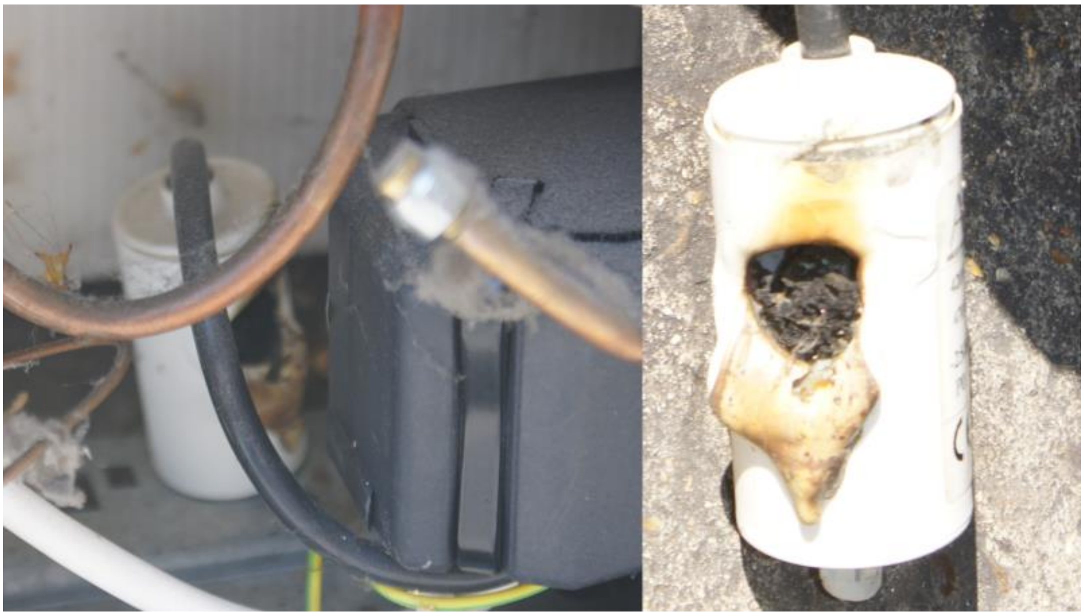


Figure 5.25 (a) and (b) Capacitor located in secured position (a) and removed but still energised (b).

Experience suggests that as appliances age, so the numbers of capacitor failures increases. As with the development of PTC switch's, the quality of manufacturing may prove to be a factor in future failures. Current standards are likely to change as the number of failures increase – see Chapter 7 for further details of modifications to capacitor design that have been introduced to reduce the likelihood of ignition.

5.6 Cut-out switch failures in integrated appliances

In the case of an integrated appliance (built in), the fridge/freezer is built into the kitchen units. Since the marketing of flat pack kitchen systems, the popularity for single fridge and/or freezer units has also increased. Many of these units could be ordered to fit the cupboards and often were provided with minimal labelling often not identifying the manufacturer of the appliance. The common design was a plastic base tray housing the compressor and associated wiring, together with a fan ventilation/cooling system. With natural airflow restricted, the cooling is provided by an electric powered fan providing blown air to the condenser coils. Fan failure can occur when a build-up of fluff, hair or other debris collects within the base area, drawn into the fan from the kitchen. Many of the failures examined have occurred in units that have been in place for over 20 years. A bi-metallic cut out switch was used on many of these models, mounted on the condenser pipe with a plastic clip. Figure 5.26. If a temperature change causes the switch to operate it is common for arcing to take place. This has resulted in numerous fires over the last three decades and continues to be the most common failure mode established for integrated appliances.

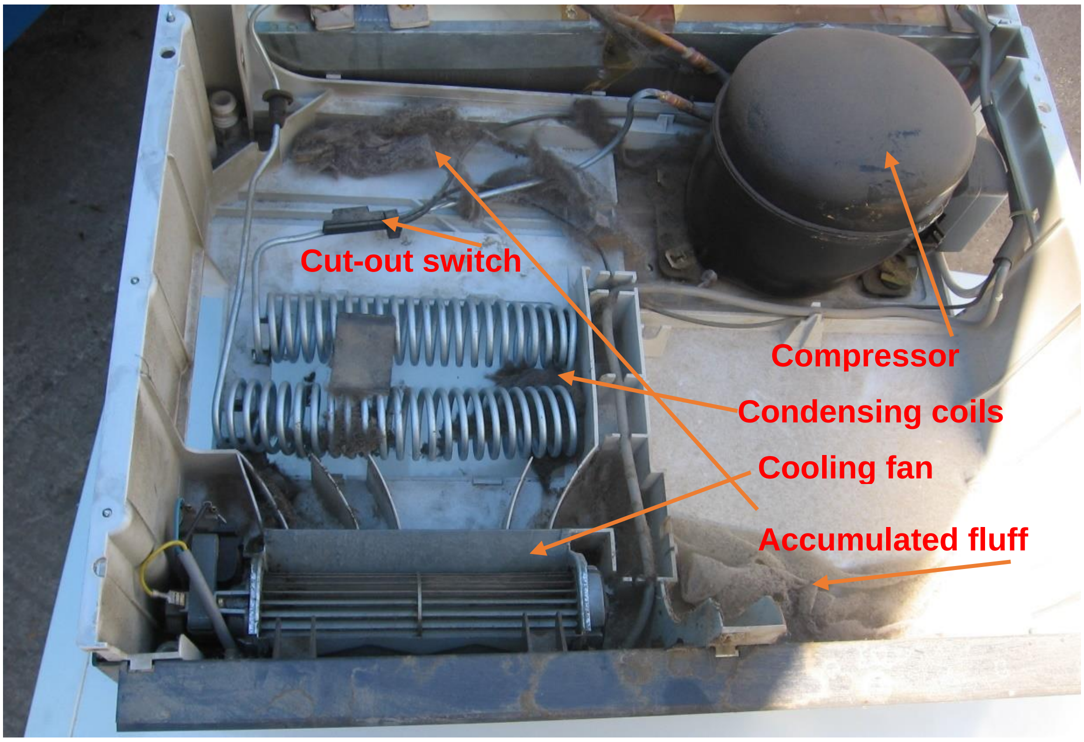


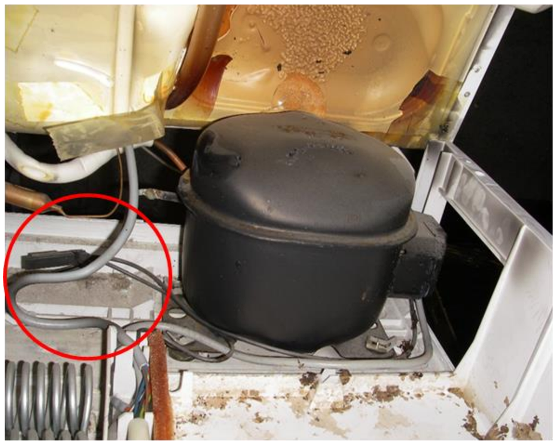
Figure 5.26 Plastic base tray housing compressor and associated components.

Figure 5.27 shows an example of the remains from an integrated appliance fire. The main components - the compressor, the condenser coils, the metal fan and fan casing are clearly visible once the frame of the fridge or freezer is removed.

Figure 5.27 The remains from an integrated appliance fire.
(LFB Fire incident no 133116151 2015)

In many fire incidents with this integrated appliance, much of the plastic crate located at the bottom of the appliance melts and burns, leaving the compressor and its components within the remaining debris. The metal refrigerator or freezer casing can normally be separated and removed to allow examination of the debris beneath.

In Figure 5.28(a) the refrigerator has been partially lifted off the plastic base. The cut-out switch can be seen circled in red. The switch is covered with a plastic case, Figure 5.28(b) which also clips to the condenser pipe. This becomes brittle with age and is often found detached from the pipe. The cover has been removed to show the switch connections inside (Figure 5.28(c) and (d)).



(a)

(b)

(c)

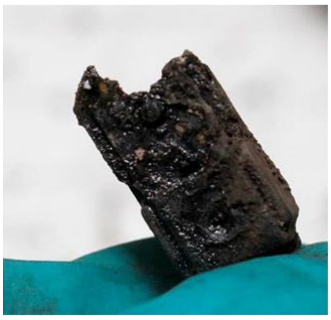
(d)

Figure 5.28 The cut-out switch used in an integrated appliance: (a) location of the switch (circled); (b) fitted inside plastic cover; switch connections with the case removed (c) side; (d) top. (Amenity site visit 06/2009)

Figure 5.29 shows some examples of failed cut-out switch's identified following fire investigations.

(a)

(b)



(c)

(d)

Figure 5.29 Examples of failed cut-out switches from integrated units that have been involved in fire incidents. (a) LFB Fire incident 133116151 10/2015

(b) LFB Fire incident 84951121 07/2012 (c) LFB Fire incident 130259131 09/2013 (d) LFB Fire incident 51438101 04/2010

The external surface of the plastic base of the ‘crate’ is normally, uniquely pressed during construction, Figure 5.30 shows this will often aid identification following a fire, and often survives post fire, located at floor level.

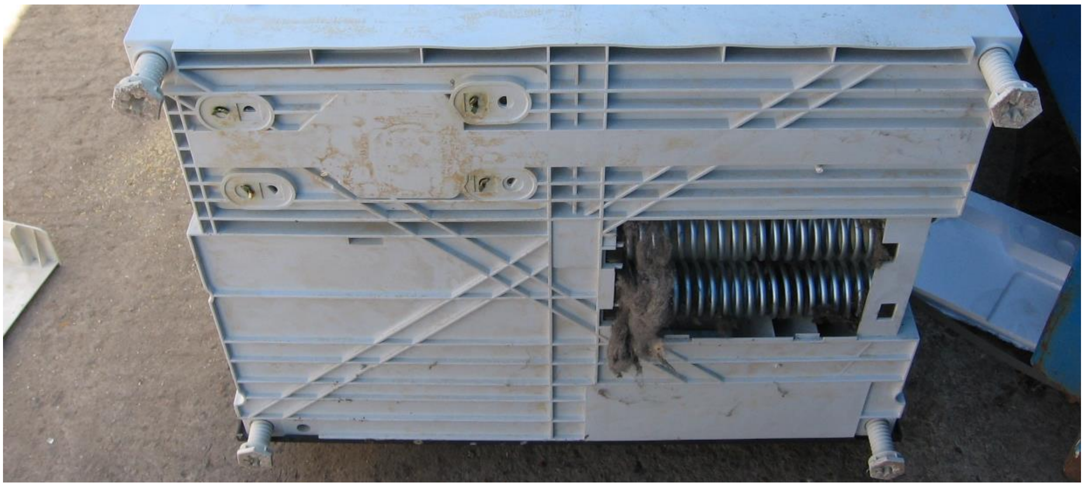


Figure 5.30 Underside of base crate showing distinct moulding pattern in plastic.

5.7 Solenoid valve failures

The solenoid is used to allow the switching of refrigerant gas between either the refrigerator or freezer compartments. The solenoid has a small coil which appears to fail and allows flammable refrigerant gas (e.g. R600a) to escape and ignite.

This specific failure mode was first identified in a fire that occurred in a built-in fridge-freezer and has been used in a number of makes and models. The fire pattern has been almost identical in each case leaving a tell-tale burn pattern followed by defined fire spread. The appliances involved are commonly placed in new build apartments/flats in multiple installations. The actual make of the failed solenoid used has been identical in each case involving different manufacturers. Figure 5.31 shows four separate examples of solenoid valve failures leading to ignition.

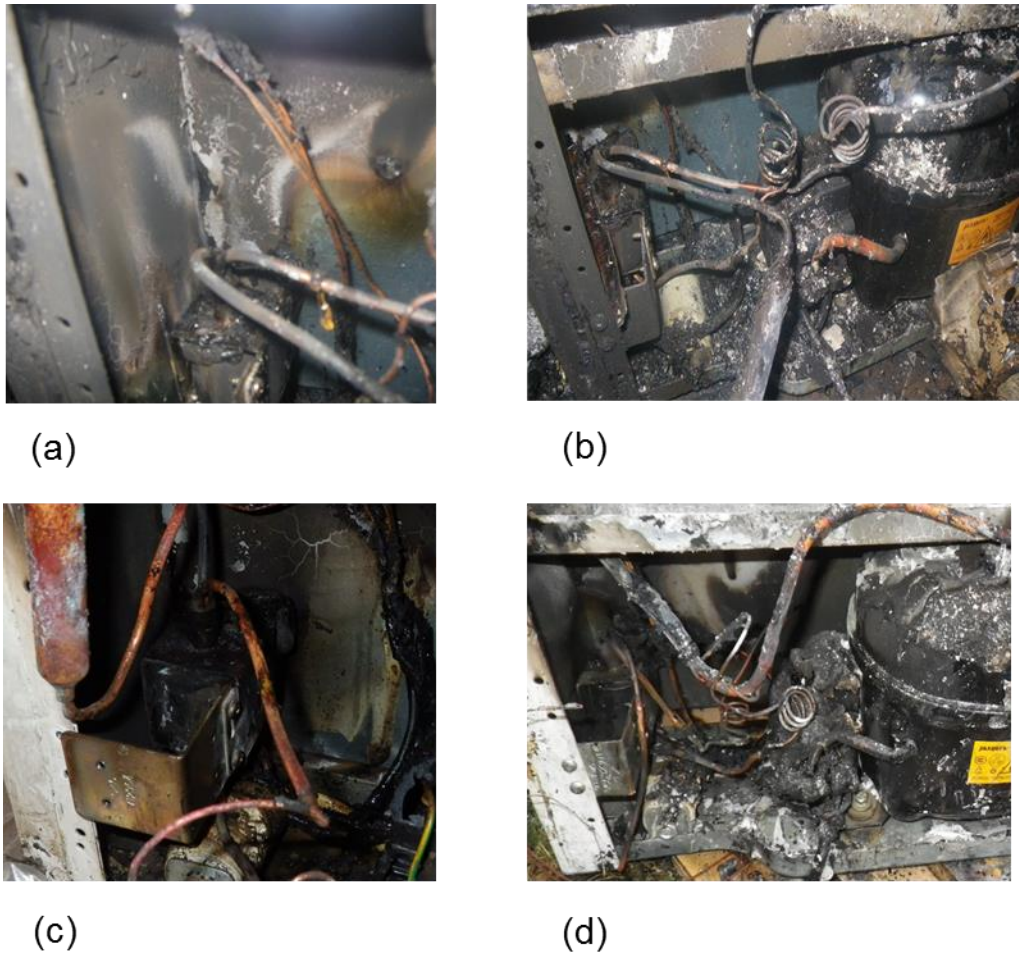


Figure 5.31 Some examples of solenoid valve failures leading to ignition.

(a) LFB Fire Incident no 137055131 10/2013. (b) LFB Fire Incident 19087111 11/2011 (c) LFB Fire Incident 101662141 08/2014 (d) LFB Fire incident 50651121 04/2012

These four examples of solenoid valve failures have resulted in ignition and damage to the compressor housing. The appliance wall behind the compressor is a metal plate. A burn pattern is left on the surface. The insulation directly above the compressor shelf is plastic and the developing fire can then spread quickly up the back of the appliance.

Following laboratory examination at Bureau Veritas, it appeared that the fire had been caused by the failure of the solenoid coil which had melted through the side wall of the solenoid valve barrel and allowed the refrigerant gas to escape, ignite, and spread the resultant fire to the surrounding materials.

5.8 Rodents

Gnawing and disturbance by rodents of electrical wiring or components within a refrigeration appliance can result in arcing and ignition. Although this type of failure is generally linked to electrical events, rodents and signs of their visiting are commonly seen when examining refrigeration appliances during fire investigations. Rodent faeces are regularly seen behind appliances. There are many cavities and spaces behind appliances that provide food, water, warmth and nesting facilities. The gnawing by rodents on wiring and plastic surfaces can be for gathering nesting materials or as part of general gnawing activity (e.g. teeth sharpening). They have even been known to gnaw through insulation and surface materials to gain access to the food within.

Figure 5.32 (a) and (b) shows an example of an appliance fire started by a rodent. (LFB Fire incident no 35889131 3/13). The smoke staining to the ceiling moulding suggests that a small fire event occurred below, on the top of the refrigerator. A closer inspection revealed the remains of a dead mouse, located on top of the circuit board, which had started the fire event. Figure 5.32(c) shows an example of gnawed insulation identified on the wiring of a fridge-freezer. The same appliance is shown in Figure 5.32(d) (LFB Fire incident no 67043121 05/12) where the capacitor has had insulation stripped by a rodent and the occupier reported a strong ‘electrical burning smell’. Arcing was observed to the damaged cable. Had the capacitor ignited, the damage caused by the rodent to both items, may not have been observed

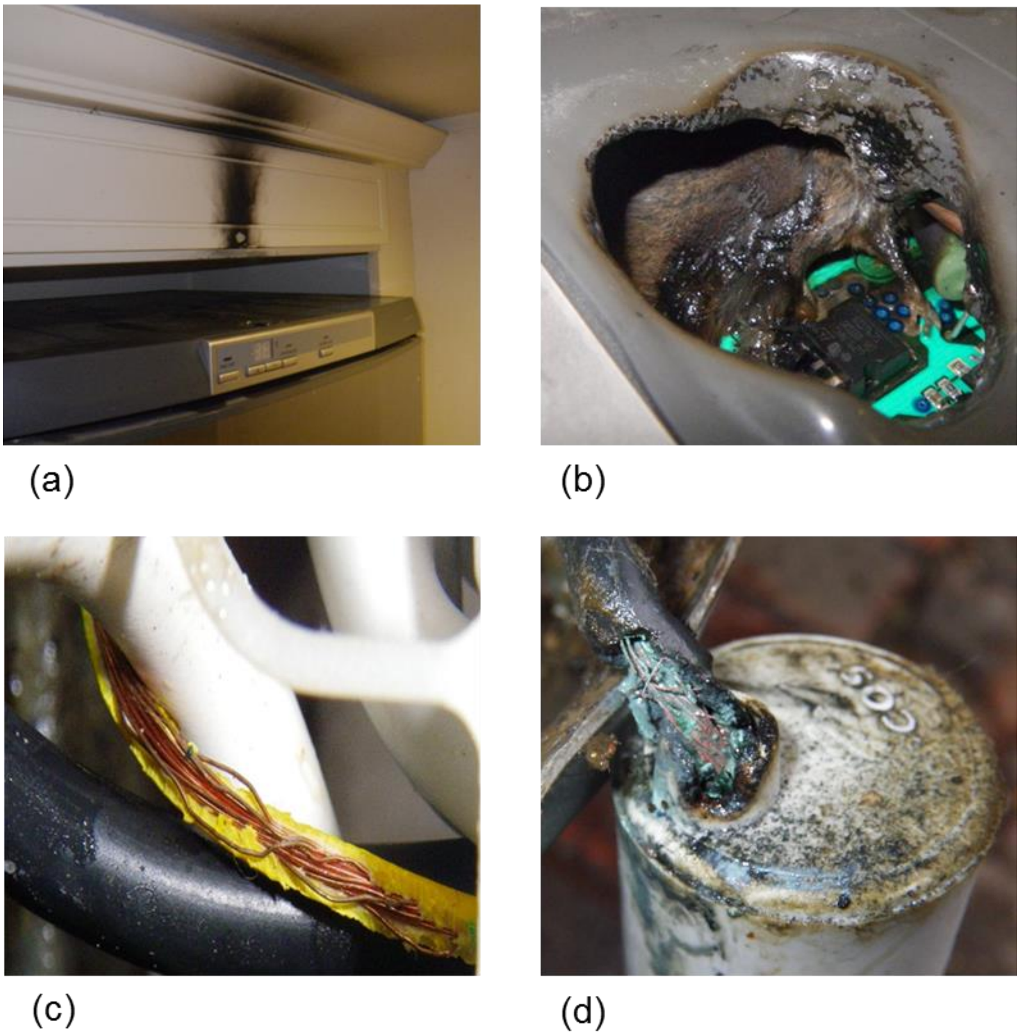


Figure 5.32. Some examples of rodent activity: (a) small fire at the top of the appliance; (b) dead mouse on circuit board; (c) gnawed electrical wiring; (d) capacitor insulation stripped by a rodent.

5.9 Summary

This chapter has examined a number of common failure modes that can lead to ignition in domestic refrigeration fires, that have been identified through the course of fire investigations: (i) Compressor starter relay failures; (ii) PTC switch failures; (iii) mechanical defrost switch failure; (iv) capacitor failures; (v) cut-out switch failures in integrated appliances; (vi) solenoid valve failures; and (vii) rodent mechanical damage. A discussion of each of these different failure modes has been given, along with examples of each type of failure that have been encountered in practice.

Should ignition occur, the severity of the resulting fire will be determined by the ease of which it is able to spread, both to other areas of the appliance and beyond the appliance. The mechanisms by which a fire in a refrigeration appliance is able to spread and escalate are the subject of the next chapter.

Chapter 6
Escalation and Fire Spread Mechanisms

6.1 Introduction to Chapter

In Chapter 5, a number of failure modes leading to ignition in domestic refrigeration appliances have been identified. Meanwhile, the analysis of appliance fire data presented in Chapter 4 suggests that, once ignition occurs, fires caused by fridge/freezers are more likely to exhibit a higher degree of fire spread and produce greater levels of damage than other types of white goods appliance (washing machine, dishwasher or tumble dryer).

Why do fires in domestic fridge/freezers appear to escalate and spread so readily following ignition? Observations taken from LFB fire investigation would suggest that changes in fridge/freezer construction materials and design with time in the UK have resulted in a more flammable construction, where faults or failures are more likely to produce a significant fire. Based upon the results of these investigations, several different fire escalations and spread mechanisms have been identified:

(i) Plastic evaporation trays

(ii) Plastic and cardboard backing materials

(iii) Polyurethane foam insulation panels

Each of these mechanisms will now be examined in more detail.

6.2 Plastic evaporation trays

For many years, the evaporation tray housed on top of the compressor was made of thin metal. Its function was to retain any condensate water until it evaporated. However, these trays would often rust and allow water to be displaced onto the compressor and on to the kitchen floor.

Figure 6.1 shows three examples of corroded metal evaporation trays observed in-situ in domestic refrigeration appliances.

Figure 6.1 Some examples of corroded metal evaporation trays used in older domestic refrigeration appliances.

The manufacturer's response to this problem was to replace the trays with plastic variants. Figure 6.2 shows an example of an (undamaged) plastic tray.

Figure 6.2 An example of an undamaged plastic evaporation tray.

Plastic trays also degrade over time. Figure 6.3 shows six examples where plastic trays have degraded allowing the liquid collected to pass onto the components located below.

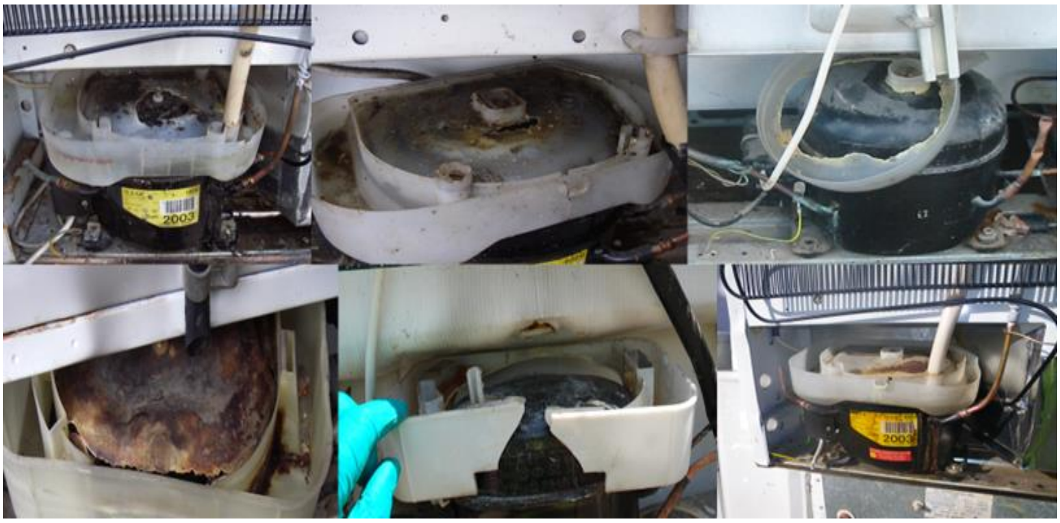


Figure 6.3 Six examples of plastic evaporation trays which have degraded allowing leakage. (Taken from research photos from amenity site visits)

The problem now is that not only do the evaporation trays fail as before, but the material used is extremely flammable, providing both a rapid flame front and burning droplets, that will increase the initial fire loading and promote flame spread to the appliance insulation. There is now the risk of water leaking onto the electrics and also onto the PTC housing.

Figure 6.4 shows a sequence of a fire test illustrating the ignition and burning behaviour of an isolated plastic evaporation tray. It can be seen that the tray is readily ignited by a flaming ignition source, burning readily whilst also melting to form drops of molten plastic which flow and form a pool fire on the floor.

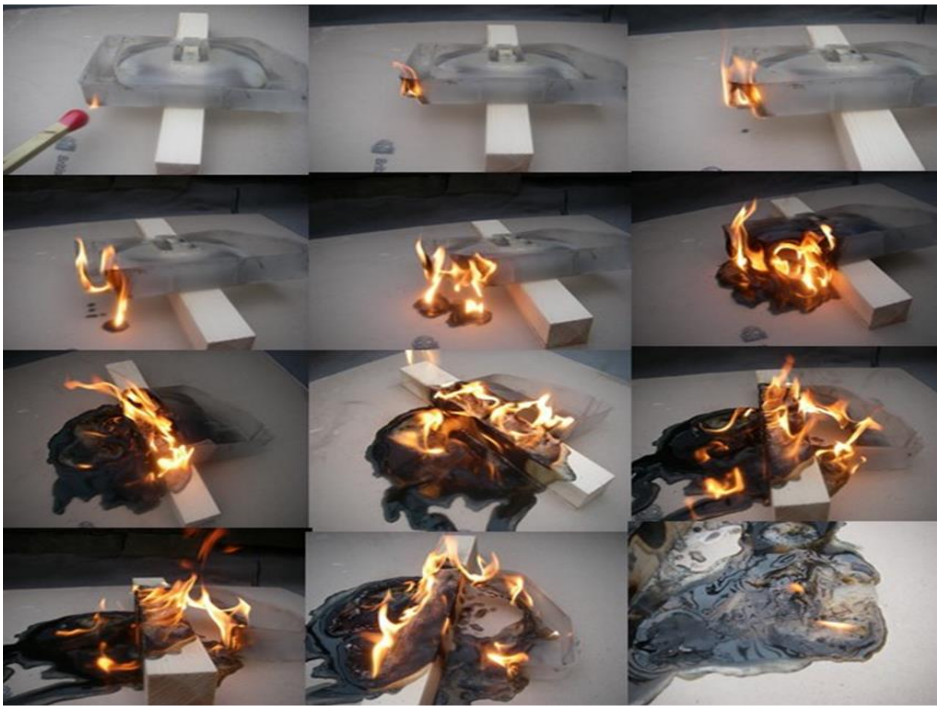


Figure 6.4 Fire test sequence illustrating the ignition and burning behaviour of a plastic evaporation tray. (New Cross fire investigation unit self-testing 09/08)

In the event of an ignition source starting a fire in the vicinity of a plastic evaporation tray, it can quickly become involved and help to spread the fire. To demonstrate this, in the test shown in Figure 6.5, a small flame has been introduced in the area next to the capacitor switch to replicate an electrical ignition of vapour, such as would occur should a PTC switch fail (see Chapter 5).

(a) (b)

Figure 6.5 Fire test involving a plastic evaporation tray: (a) small flame in compressor housing; (b) the fire involves the plastic tray and spreads up the rear wall of the appliance. (LFB Refrigerator burn tests Wethersfield Essex Nov 2007)

From a small ignition source next to the PTC compressor switch, the flame rapidly spreads across the ceiling of the compressor housing before igniting the evaporator tray and spreading up the rear wall of the appliance. As the developing fire spreads vertically and also horizontally above the compressor, unburnt droplets and molten plastic from the evaporator tray, pool on the floor surface where they can be ignited by other flaming droplets and radiated heat from the fire.

There are currently no regulations in the UK governing the size, shape or location of the evaporator container. A recent observed change (see figure 6.6) is for the tray to be raised above the compressor rather than be in direct contact. The size of the tray appears to have grown in area, but is shallower - perhaps to provide a greater surface area for evaporation. Whilst the raising of the tray may mitigate the problem of heat degradation, it is perhaps questionable how well the evaporation from the tray now works. Newer compressors on the market often generate less heat.

Figure 6.6 An example of a raised plastic tray in a modern appliance.

In 2005 a fatal fire involving a fridge/freezer resulted in a thorough investigation by the Sheffield Coroner (South Yorkshire Fire Brigade 2005). In order to assist the investigation, the manufacture provided a similar model of appliance for comparison testing. In the opinion of the forensic expert, appointed by the court, the fire originated at low level at the rear of the appliance, around the compressor area, and spread upwards and through the fridge. The severe development of the fire was attributed to the ignition of the plastic evaporation tray and/or the plastic coating on the foam insulation.

6.3 Plastic and Cardboard Appliance Backing Materials

The metal panels used in older fridge/freezer designs as part of the frame, covered the insulating materials within forming an almost impenetrable fire barrier. This construction method has slowly been replaced in many appliance designs. There seems to have been an interim period in the construction of modern appliances from the 1980’s to the late 1990’s when either metal foil or foil backed cardboard was used as a rear wall covering of the insulating foam (see Figure 6.7). This material was used to provide a barrier against moisture ingress.

Figure 6.7 An example of metallised cardboard covering the rear wall foam insulation of an appliance.

Figure 6.8 shows an example of flame spread up the back of appliance that can be dated to pre-1993. A plastic film covers the metallic foil, which in turn covers the foam insulation. In this example, the ignition, due to defective compressor start switch, produced a small flame, which ignited the plastic external covering. The resulting fire melted and charred the plastic to expose the metal foil, but did not ignite the foam insulation beneath. This flame spread pattern is almost never seen in more modern appliances, which normally fully involve the insulation material following any similar ignition scenario.

Figure 6.8 An example of flame spread up the rear of a pre-1993 appliance, backed by a plastic film covering metal foil, which has prevented ignition of the foam insulation material. (LFB Fire incident no 10885122 06/2012)

From the late 1990's a plastic - polyethylene/polypropylene back panel material known as a "twin-wall" began to be used (Figure 6.9). "Twin-wall" plastics are also often present as lining materials in the compressor compartment.

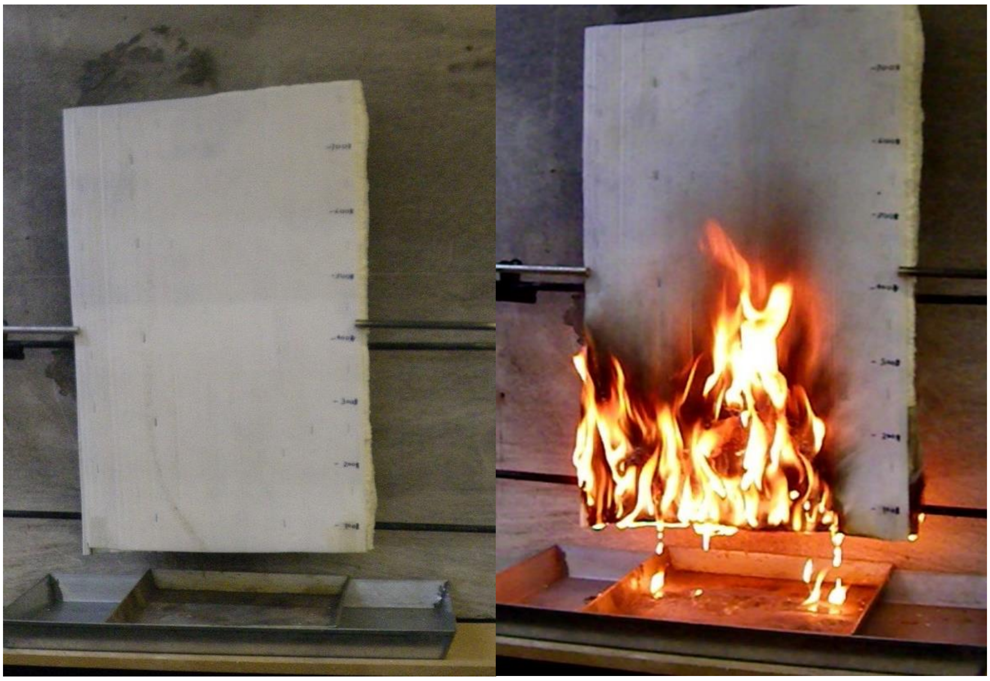
Figure 6.9 The twin-wall back panel cut to provide an outlet for water to drain through the rear wall of the appliance. The appearance is similar to joined plastic straws.

Table 6.1 Summary of the fridge-freezer back panel materials tested in the fire spread experiments.

Panel Type	Material Description
P1	PU foam (50 mm) + PE/PP "twin-wall" panel (2.4 mm)
P2	PU foam (50 mm) + polymer foam film (10-20 mm) + foil/cardboard laminate panel (0.4 mm)
P3	PU foam (50 mm) + ABS panel (1.2 mm)
P4	PU foam (50 mm) + foil/cardboard laminate panel (0.5 mm)

Fire tests have revealed that such plastic "twin-wall" and cardboard backing materials, when used in fridge/freezers, can become ignited very easily and then promote extremely rapid flame spread to involve insulation panels, whilst producing intense heat and large volumes of toxic smoke (Vaughan-Davies, 2012). A number of samples of rigid, C-pentane blown, polyurethane (PU) insulation foam together with materials typically used (as alternatives to steel) to cover the back panel of fridge/freezer appliances, in the UK, were obtained and tested. Table 6.1 summarises the characteristics of the different back panel samples that were examined. The different types of thin back panel covering material tested included several samples of “twin-wall” polyethylene (PE) / polypropylene (PP) thermoplastic, along with other panels constructed from foil/cardboard and Acrylonitrile butadiene styrene (ABS) plastic.

In order to carry out the tests, the thin backing material (e.g. 2.4 mm thick “twin-wall”) were mounted on top of the polyurethane insulation foam (nominally 50 mm thick) to form a composite back panel (as would be found in a fridge-freezer). Fig 6.10 (a) illustrates this. The bottom of the panel was then exposed to a small flame (via a wax taper) fig 6.10(b) for a few seconds to see if it could be ignited. A polyester tensioned thread was mounted 0.5 m above the ignition point at the bottom edge of the panel. Should flame spread up the panel occur, the failure of the thread would then provide a uniform indication of the time after ignition for the flame to travel this distance.



(a) (b)

Fig 6.10 2.4mm thick “twin-wall” panel polyurethane insulation foam (a) mounted on top of the polyurethane insulation foam to form a composite back. (b) Results following ignition with a wax tapered flame.

(a)

Fig 6.11 Twin-wall panel mounted on insulating foam viewed sideways.

A series of tests were performed using the different back panel specimens, with the open back panel to view. In everyday operation, the back of a fridge-freezer unit will typically be positioned in close proximity to the surface of a wall.

A second set of experimental tests were therefore also performed with the back panel located 50 mm away from a (non-combustible) wall, to allow the effect of doing this on the initial growth of the fire to be examined. In order to better facilitate comparison between the different test results, the time from ignition to the failure of the thread (0.5 m above) has been used to calculate an average rate of flame spread.

The results that were obtained for the tests with the back panel facing forward, are summarised in Table 6.2. They illustrate the relatively high flame spread rates that were produced by many of the back-panel materials tested. Many of the covering materials rapidly melted away, allowing the underlying foam insulation to become involved. The highest rate of flame spread was observed for the thin polymer foam film and foil/cardboard laminate panel (P2). The majority of the PE/PP "twin-wall" panels tested (P1) produced medium fire growth rates. The lowest fire spread rate was observed for the ABS panel (P3), which produced flaming drips early in the test and but did not melt away and tended to protect the foam insulation, whilst the foil/cardboard laminate panel (P4) performed best of all since it could not be ignited.

Table 6.2 Summary of the fridge-freezer back panel fire spread test results obtained with the back panel facing forward.

Specimen	Panel Type	Ignition?	Time to thread melting (s)	Rate of flame spread (mm/s)
S0	P1	Yes	81	6.2
S1	P1	Yes	206	2.4
S2	P2	Yes	64	7.8
S3	P1	Yes	121	4.1
S4	P1	Yes	97	5.2
S5	P3	Yes	187	2.7
S6	P4	No	-	-
	Mean		126	4.7

Table 6.3 Summary of the fridge-freezer back panel fire spread test results obtained with the back panel located 50 mm from a wall.

Specimen	Panel Type	Ignition?	Time to thread melting (s)	Rate of flame spread (mm/s)
S0	P1	Yes	40	12.5
S1	P1	Yes	148	3.4
S2	P2	Yes	82	6.1
S3	P1	Yes	149	3.4
S4	P1	Yes	75	6.7
S5	P3	Yes	109	4.6
S6	P4	No	-	-
	Mean		100	6.1

The corresponding tests results with the back panel located 50mm from the wall are given in Table 6.3 In this case the highest flame spread rates were exhibited by the “twin-wall” panels (P1). Comparison of these results with those found with the back panel open, (facing forward), would suggest that the fire spread rate is generally being enhanced by the close proximity of the wall, due to re-radiation of heat from the wall, back to the fire on the back panel, and by creating a chimney effect increasing the airflow drawn into the flue like channel that is formed.

Figure 6.12 shows an example illustrating the ignition behaviour and development of the flame observed in one of the tests performed on the twin-wall backing material. The twin-wall material readily ignites upon application of a naked flame (Figure 6.12 (a)). Subsequent flame spread after 75 s, both upward and downward (Figure 6.12 (b)). The “twin-wall” melts away to expose PU foam below which easily ignites and burns vigorously. The flame has grown rapidly in extent to reach close to the top of the panel, after just a few more seconds (Figure 6.12 (c)).

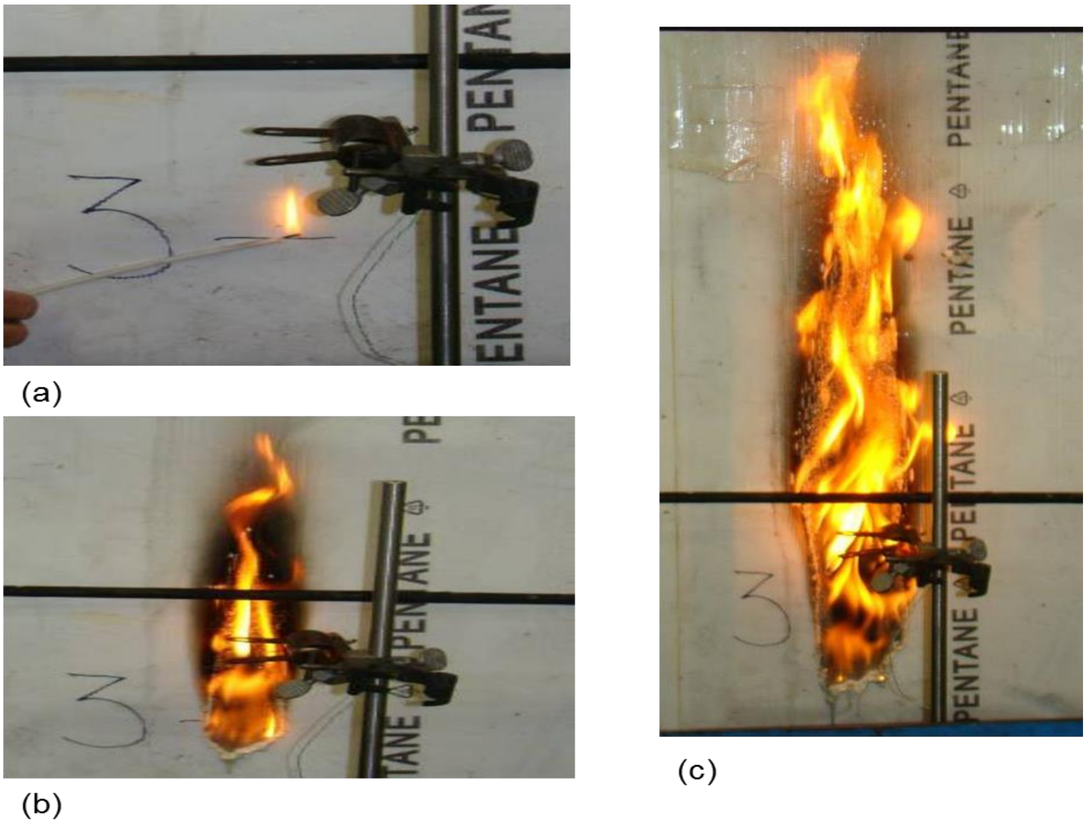


Figure 6-12 Burning behaviour of twin-wall backing material; (a) application of ignition source; (b) initial development of flame after 75 s; (c) rapid spread of flame a few seconds later.

London fire brigade, in conjunction with the UK Building Research Establishment (BRE) have also recorded video footage comparing a plastic backed fridge-freezer fire versus a metal backed fridge-freezer fire (LFB, 2015). The footage clearly illustrates the difference between the two cases, in terms of the growth rate and intensity of the resulting fires (which were started in the compressor compartment at the base of the fridge-freezer). For the plastic backed fridge-freezer, the fire spreads rapidly up the rear plastic panel of the unit, becoming well involved after 90 seconds (and had to be extinguished after 150 seconds, before it could overwhelm the test facility). For the metal backed fridge-freezer, the fire is unable to spread up the steel back panel, but instead remains largely restricted to the compressor compartment (and later self-extinguished, after 20 minutes).

6.4 Polyurethane Foam Insulation Panels

The early slab constructed internal insulation panels used in the UK have now been replaced by blown hydrocarbon foams – typically rigid polyurethane foam (Figure 6.13).

Figure 6-13 Removing the external metal sidewall reveals the hydrocarbon blown polyurethane foam beneath.

Based upon environmental and cost considerations the use of polyurethane foam in refrigeration appliances is highly attractive to manufacturers, since it acts as a very effective insulation material, which is able to minimise heat transfer and cooling losses and maximise the efficiency of the appliance, helping to meet targets for reducing climate change. CFCs used to be used as blowing agents to form the foam, but environmental considerations (damage to the ozone layer) led to production of CFCs being prohibited and the introduction of hydrocarbons, such as cyclopentane, being used as the foam blowing agent (Nistitani, 2016). These do not damage the ozone layer, but they are flammable, and hence they further increase the flammability of the insulation.

A study carried out by the UK Environment Agency (2011) examined the flammability of a number of insulation foam samples, that were produced using a hydrocarbon blowing agent, cut from 20 fridge/freezer appliances. They observed that the thickness of the foam insulation panels used in these appliances was generally between 40 – 100 mm. The samples obtained from each appliance were cut into 3 strips each 250 mm long, 20 mm wide by 10 mm high and tested in accordance with European Union (2008) Commission Regulation (EC) No 440/2008 – Annex Part A, Test Method A.10 Flammability (Solids). This test method requires that a hot burner flame be applied to ignite the sample strip at one end. After the flame has burned an initial distance of 80 mm, the time for the flame to burn the next 100 mm is measured and used to characterise the rate of burning. Test method A.10 states that a substance is to be considered “highly flammable” if the time of burning for the flame to travel 100 mm is less than 45 seconds. All of fridge/freezer foam samples tested burned the required distance (100 mm) in less than 20 seconds and hence should be considered “highly flammable”. Hence, the UKEA study concluded that hydrocarbon blown fridge-freezer insulation foam should be officially classified as hazardous waste when sent for disposal. The results also suggested that the high burning rates seen were related to the quantity of hydrocarbon blowing agent content released from the foam.
Fire tests have shown that untreated rigid polyurethane foam insulation offers little resistance to ignition and burns very rapidly, generating high heat release rates, thick smoke and toxic gases (Vaughan-Davies, 2012). There are extensive quantities of such materials present in a typical refrigerator creating a high fire load.

The nominal density for rigid polyurethane foam used as insulation in refrigeration appliances is typically 54 Kg/m^3 the heat of combustion is 26 Mj/kg (Nimmo 2012). These values can be used to help obtain an estimate of the total heat release that could be generated if all the rigid polyurethane foam present in a typical fridge-freezer appliance were to be burned. Assuming that a typical fridge-freezer unit has the approximate dimensions: 2 m high, 0.6 m wide and 0.6 m deep, that the foam insulation is 50 mm thick, and that it can be treated as being made up of seven panels along the back, two sides, front (in doors), top, bottom and middle (between the fridge and freezer), then the total mass of foam insulation would be approximately 15.9 kg (see Table 6.4). The estimated total heat release that generated for a whole fridge-freezer appliance would then be:

Total Heat Release = 26 MJ/kg × 15.9 kg = 413 MJ   Eqn.6.1

Table 6.4 Estimated mass of rigid polyurethane foam insulation that could be present in a typical fridge/freezer appliance.

Foam Panel	Dimensions	Volume	Mass (kg)
Back	2.0 m × 0.6 m × 0.05 m	0.060	3.24
Side 1	2.0 m × 0.6 m × 0.05 m	0.060	3.24
Side 2	2.0 m × 0.6 m × 0.05 m	0.060	3.24
Front (Doors)	2.0 m × 0.6 m × 0.05 m	0.060	3.24
Top	0.6 m × 0.6 m × 0.05 m	0.018	0.97
Bottom	0.6 m × 0.6 m × 0.05 m	0.018	0.97
Middle	0.6 m × 0.6 m × 0.05 m	0.018	0.97
Total		**0.294**	**15.9**

If the thickness of the foam insulation used were 100 mm, instead of 50 mm, then the total mass of foam insulation and consequent total heat release would be doubled. Hence, we can estimate that the total heat release generated, if all the polyurethane foam in a typical fridge/freezer appliance were to burn, would be in the range of 400 – 800 MJ. This range is broadly consistent with the total heat release for fridge-freezer fire tests R1 (537 MJ) and R2 (404 MJ) reported by Babrauskas (2006), based upon the experimental test data obtained by Hietaniemi et. al (2001). Hietaniemi et. al (2001) also observed that none of the plastic materials used in the appliances they tested were protected by flame retardants.

6.5 Summary

In this Chapter, several mechanisms that produce fire escalation and flame spread in domestic refrigeration appliances have been identified - all of which result from the usage of plastics in the appliances construction. Firstly, in the event of ignition, plastic evaporation trays, located above the compressor, can quickly become involved and help to spread the fire at the back of the appliance and to internal insulation material. Secondly, the use of flammable plastic backing materials, such as twin-wall, at the rear of fridge/freezers can promote rapid flame spread from the potential ignition sources located in the compressor housing up the back of the appliance and will also serve to rapidly involve the polyurethane insulation foam that lies beneath. Finally, once involved, the large quantities of hydrocarbon blown, rigid polyurethane insulation foam present in modern refrigeration appliances provides an extensive fire load, which can burn very rapidly, generating high heat release rates and total heat release and producing significant quantities of thick smoke and toxic gases. These mechanisms help to explain why fires involving domestic refrigeration appliances are more likely to exhibit a higher degree of fire spread and produce greater levels of damage and casualties than are found for fires involving other types of white goods appliance.

Chapter 7
Discussion

7.1 Introduction to Chapter

The refrigeration appliance is almost unique in its domestic setting as it is one of the few appliances which runs continuously and is not designed to be isolated at night or when left unattended. Hence, it is extremely important that domestic refrigerators be designed and manufactured so that not only the chance of fire is very low, but that should a fire occur it then remains contained within the appliance and not be able to spread. However, the results from Chapters 4, 5 and 6 suggest that not only are there a number of potential ignition mechanisms for fridge-freeze fire which are occurring in practice, but that if ignition should occur then a higher proportion of fires in fridge/freezers spread beyond both the appliance and the room of origin than is the case for the other types of appliance and that they are more likely to result in high levels of fire damage. This chapters discusses why this is the case, making comparisons between Great Britain and USA (in terms of both fire casualties and standards/regulations), and suggests measures that can be adopted to reduce the likelihood and consequences of domestic refrigeration fires.

7.2 Why do fridge-freezer fires tend to result in higher levels of damage?

Table 7.1 shows a comparison of the peak heat release rates that have been observed for the four different types of white goods appliance considered, taken from Babrauskas (2016), based upon the results of the fire tests performed by VTT and EFRA. It is clear that, as a result of the greater levels of polyurethane foam insulation material and other plastics being used in their construction, the heat release rate exhibited by fires involving fridge/freezers can be significantly higher than those displayed by the other types of appliance.

As explored in Chapter 6 fridge/freezer fires are also more likely to spread rapidly in case where a plastic backing material has been used at the rear of the appliance.

Table 7.1 Typical peak fire heat release rates observed for different types of white goods appliance.

Appliance type	Peak heat release rate (kW)
Fridge-freezer	852 – 2125
Tumble dryer	525
Dishwasher	345 – 476
Washing machine	221 – 431

Thus, as a consequence of the fire spread mechanisms identified and high heat release rates involved, once ignited, fridge-freezer fires are more likely to produce an intense fire which can spread both beyond the appliance and the room of origin and produce greater levels of fire damage than is the case for the other types of white goods appliance.

7.3 Comparison between Great Britain and USA

Table 7.2 provides a comparison between the annual average number of fires, fire casualties and the probability of a fire and the risk of a fire casualty (estimated using available data on the number of households having refrigeration appliances (Office of National Statistics, ONS 2015, U.S. Energy Information Administration, 2009) due to domestic refrigeration appliances in the United States (Hall 2012) and Great Britain (DCLG 2005-2015).

The estimated probability of ignition due to refrigeration appliances is of a similar magnitude for both nations. However, the estimated annual risk of a fire casualty due to refrigeration appliances is approximately seven times higher in Great Britain than in the United States.

Table 7.2 A comparison between the annual average number of fires and casualties, annual probability of fire and risk of fire casualties due to domestic refrigeration appliances in the United States and Great Britain.

Country	Average number of fires (per year)[1,2]	Average number of casualties (per year)[1,2]	Number of households with a refrigerator[3,4]	Probability of a fire (per year)[5]	Risk of a fire casualty (per year)[5]
United States	1710	58	113,400,000	1.5×10^{-5}	5.1×10^{-7}
Great Britain	335	88	25,362,000	1.3×10^{-5}	3.5×10^{-6}

[1]Based upon an annual average of 2006-2010 home fires, in the US, involving a refrigerator or freezer [5].
[2]Based upon an annual average of fires and casualties 2009/10 to 2012/13, in residential dwellings in Great Britain, with fridge/freezers given as the source of ignition [1, 21].
[3]Based upon Residential Energy Consumption Survey (RECS) Data, Table HC3.1 Appliances in U.S. Homes, by
Housing Unit Type, 2009. [20]
[4]Based upon data for England from ONS Family Spending 2015 – Table A48: Percentage of households with
durable goods by UK countries and regions, 2012 to 2014. [14]
[5]Estimate assumes one appliance per household.

Similarly, the annual casualty rate (per 1000 fires) due to domestic refrigeration fires, is nearly eight times higher in Great Britain than in the United States (see Figure 7.1) This data suggests that a significant difference exits between the two countries with regard to the occurrence of severe refrigeration fires. Why?

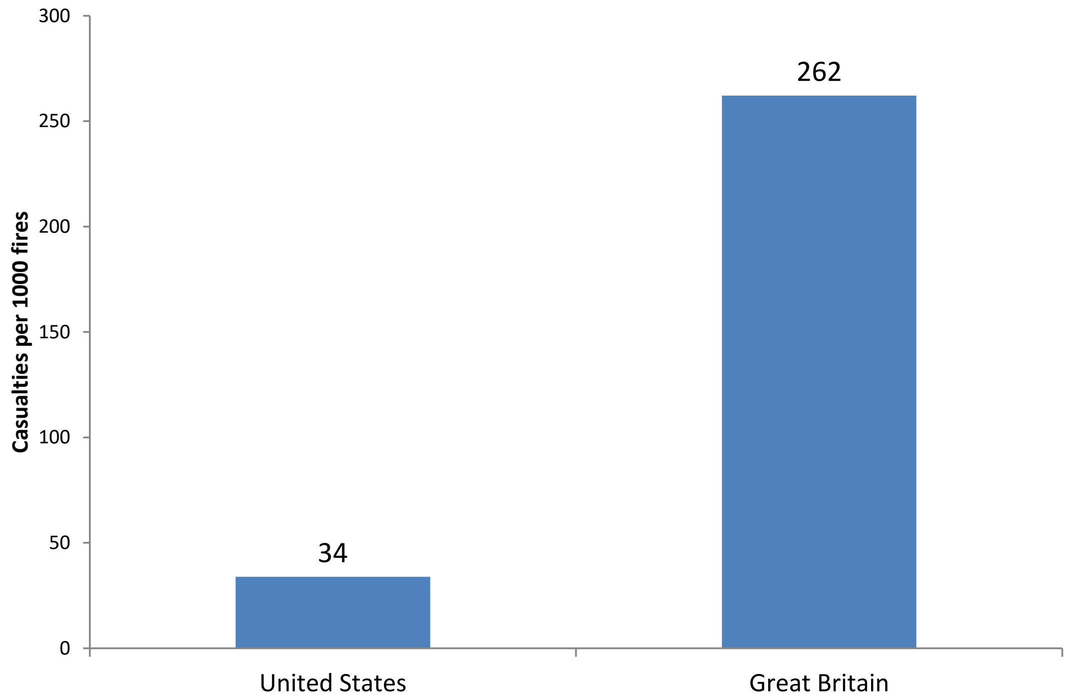


Figure 7.1 A comparison between the fire casualty rate (per 1000 fires) due to domestic refrigeration fires for USA and Great Britain.

A comparison between the two countries suggests that a number of significant differences in refrigerator appliance design and construction have arisen. For example, refrigerators in the USA still have a largely steel housing construction (casing and back wall) and use metal evaporation trays. They also tend to use higher quality components (e.g. protective P2 capacitors) that are less likely to fail and act as sources of ignition, and have a policy of surrounding potential ignition sources in metal box containments, isolating then from other flammable items. Babrauskas (2016) also suggests that “European appliance styles are different”, and that "local standards are such as to permit appliances of greater flammability in Europe". Consequently, he states that existing heat release rate data, which has been obtained for fires involving European refrigerators, must not be applied to appliances used in North America.

7.4 Problems with Refrigeration Appliance Fire Safety Standards

The concerns and problems with the current fire safety of domestic refrigeration appliances in the UK can be linked to the current safety standard for refrigeration appliances BS-BS 60335-2-24 (EN)

For example, the standard allows plastic backs to be used at the rear of the appliance. Currently the test for the appliance backing material only requires glow wire test to be performed - placing a hot glowing wire on the test sample for 30 seconds. This is intended to simulate an overheating component that comes into contact with the back of the appliance. However, the plastic will typically just melt rather than catch fire and hence pass the test. Such a test doesn't adequately replicate what would happen if the backing material was exposed to a naked flame, where it can ignite and produce a self-sustaining flame which can then spread rapidly up the back of the appliance, as has been shown in Chapter 6.

From 2019, all UK/EU refrigeration appliances will be required to meet a new tougher standard with backing material tested using a naked flame rather than the glowing wire test. However, in-spite of the mounting evidence for the need for such a change in the standard, it met with significant resistance from some members and consequently it took a number of years before the standards committee could approve it.

In the UK (and EU) the only real driver for improving the fire safety design of appliances is to legislate through changes to standards. The failure of electrical components is always a possibility - the resulting fire growth following a failure is also predictable. The solution is often financially achievable, but it falls to standards to determine and set the changes. European standards are largely controlled and set by manufacturers and their representatives, placing a potential impediment to change. In contrast, in the USA design and regulation of refrigerators is driven by the insurance industry (via the Underwriters Laboratory) and threat of litigation. This difference in regulatory system would appear to be the most likely explanation for the differences in refrigerator appliance design and construction that are seen between the UK and USA.

7.5 Measures for Reducing the Risk

Consideration of the potential ignition sources and escalation mechanisms observed during LFB fire investigations and the differences in UK and USA fridge/freezer construction suggests that the following design measures could be used by manufacturers to reduce the likelihood and severity of fridge/freezer fires:

7.6 Using Fault Tolerant Components

Fault tolerant components (e.g. capacitors) and PCB boards should be used to reduce the likelihood of component failures leading to ignition. For example, in the USA manufacturers have tended to use compressor motor capacitors with a higher (S2) safety class that are more fault tolerant. In accordance with IEC 60252-1 [31], the four the classes of safety protection for a motor capacitor are defined as:

- S0 (formerly P0): Indicates that the capacitor has no specific failure protection
- S1 (formerly P1): Indicates the capacitor may fail in either open circuit or short circuit.
- S2 (formerly P2): Indicates the capacitor has been designed to fail in the open circuit mode only.
- S3: Indicates that the capacitor is of segmented film construction (designed to enhance self-healing of dielectric breakdown and limit the area of damage).

The S3 has been in production and in limited use, but the both the US and UK/EU have not yet recommended its use. The S2 safety class capacitors are currently specified which have a "fail safe" pressure sensitive design. This is intended to expand and disconnect the electrical supply before the pressure reaches a point where the capacitor could rupture or explode, and eject the burning capacitor contents, hence reducing the likelihood of a failed compressor motor capacitor acting as an ignition source (see Figure 7.2). The number of identified failures in S2 capacitors appears to be growing and further research has been suggested to differentiate between slow and rapid developing failures.

Figure 7.2 A fault tolerant protective S2 capacitor.

7.7 Containing potential ignition sources in a fire resisting enclosure

Internal components which may fail and act as ignition sources, such as capacitors, should be placed away from insulation material, behind fire resisting barriers and in fire resisting enclosures to prevent fire spread (Figure 7.3). These protective measures have been followed in the US for some time but not so here in UK/EU. Recent amendments however have allowed capacitors to be fitted without this protection provided they are up to the current standard.

Figure 7.3 An American appliance with both the capacitor and the defrost timer switch mounted in a white fire resisting box within an all metal compressor housing and metal evaporator tray.

7.8 Using grill guards

Grill guards, which are already used on many commercial fridge-freezers, could be introduced to inhibit rodent access to the interior of the fridge and the compressor housing (Figure 7.4).

Figure 7.4 Grill guard across compressor housing.

7.9 Using metal or fire resisting evaporation trays

Evaporation trays should be constructed from metal or other non-combustible materials, as seen in figure 7.5 this would prevent them from igniting and assisting the spread a fire.

Figure 7.5 Example of a metal evaporation tray positioned above the compressor.

7.10 Interior compartmentation

Interior compartments could be introduced to put components in steel cavities to prevent fire spread to the insulation foam (Figure 7.6). A simple light weight metal plate could also be fitted to separate the compressor motor and housing from the rest of the unit to prevent fire spread.

Figure 7.6 Example of using interior metal compartmentation to prevent fire spread from any potential component failure reaching the insulating material.

7.11 Fire retardant insulation foam

Fire retardants could be added to the insulation foam or applied to insulation surfaces to inhibit flame spread. However, retardants can also have drawbacks such as increasing smoke flammability/toxicity and the eventual severity of a fire and may also have an adverse environmental impact. Non-flammable blowing agents are also being developed but are not yet in substantial commercial use.

7.12 Fitting a non-combustible covering at the back of the appliance

A metal plate or other non-combustible covering should be used to cover all insulating material at the back and beneath the appliance to prevent fire spread into the insulation. (Figure 7.7). The backing or covering material should be sealed, with no gaps or penetrations which could allow flame spread to the interior insulating material.

Figure 7.7 Example of a fridge-freezer appliance fitted with a metal back.

If this process were carried out, the risk from external component failure and ignition of insulation would also be severely limited.

7.13 Summary

Fridge-freezer construction currently uses greater levels of polyurethane foam insulation material and other plastics in the building stages. As a consequence of the fire spread mechanisms identified, and high heat release rates evolving from insulation once ignited, there is a greater risk of fire spread both beyond the appliance and the room of origin. This will lead to greater levels of fire damage than the other types of white goods appliances. In slowing down or preventing the rapid development and fire spread, greater opportunity exists for people to become aware and escape from the developing fire.

Based upon the ignition and fire spread mechanisms examined in previous chapters and the differences between UK and USA fridge-freezer construction a number of ways in which fridge-freezer fire safety could be improved have been identified.

Chapter 8
Conclusions and Future Work

8.1 Fire Investigation Methodology

A methodology collecting information from the scene of fire investigations involving domestic refrigeration appliances over the past decade, has been developed and used here to identify possible ignition and fire spread mechanisms occurring in domestic refrigeration fires. In many fire authorities, the level of fire investigation is often determined by loss of life or serious injury. The recording of data for statistical purposes generally falls to the fire officer who was responsible for extinguishing the fire. This minimal data collection often provides no details of the failure mechanism and adds little to the collection of data that can prevent further fires. The investment into better training, awareness, and the recording of information of greater value should be seen as an investment for reducing the number accidental fires. It is commonly the case that far greater information and evidence of failure and causation, is obtained from small incidents than from major events. Fire investigators will confirm that much of their practical skill and knowledge is learnt from smaller incidents.

8.2 Appliance Fire Data Analysis

The generic reasons for the cause and spread of domestic refrigeration fires has been examined using data obtained from the analysis of National data sets available in Great Britain and from the specific data from fire investigations carried out in London.

Analysis of these incidents suggests that, once ignition occurs, fires caused by fridge-freezers are more likely to exhibit a higher degree of fire spread and produce greater levels of damage than other types of white goods appliance (washing machine, dishwasher or tumble dryer). Nearly 80% of fires with fridge-freezers as the source of ignition, spread (caused fire damage) beyond the first item involved, whilst almost 40% spread beyond the room of origin (usually the kitchen). Fires involving fridge-freezers also displayed a far higher casualty rate per fire (340 casualties per 1000 fires) than was found for the other types of appliance.

8.3 Common Failure Modes Leading to Ignition

A number of common failure modes that can lead to ignition in domestic refrigeration fires that have been identified through the course of fire investigations:

- (i) faulty starter relays.
- (ii) failing PTC switches.
- (iii) mechanical defrost switch failures.
- (iv) capacitor failures.
- (v) cut-out switch failures in integrated appliances.
- (vi) solenoid valve failures.
- (vii) rodent mechanical damage.

An examination of each of these different failure modes has been made, along with examples of each type of failure that have been encountered in practice.

8.4 Escalation and Fire Spread Mechanisms

Should ignition occur, the severity of the resulting fire will be determined by the ease of which it is able to spread, both to other areas of the appliance and beyond the appliance. Several mechanisms that produce fire escalation and flame spread in domestic refrigeration appliances have been identified - all of which result from the usage of plastics in the appliances construction. Firstly, in the event of ignition, plastic evaporation trays, located above the compressor, can quickly become involved and help to spread the fire at the back of the appliance and to internal insulation material. Secondly, the use of flammable plastic backing materials, such as twin-wall, at the rear of fridge/freezers can promote rapid flame spread from the potential ignition sources located in the compressor housing up the back of the appliance and will also serve to rapidly involve the polyurethane insulation foam that lies beneath. Finally, once involved, the large quantities of hydrocarbon blown, rigid polyurethane insulation foam present in modern refrigeration appliances provides an extensive fire load, which can burn very rapidly, generating high heat release rates and total heat release and producing significant quantities of thick smoke and toxic gases. These mechanisms help to explain why fires involving domestic refrigeration appliances are more likely to exhibit a higher degree of fire spread and produce greater levels of damage and casualties than are found for fires involving other types of white goods appliance.

8.5 Reasons for the Severity of Domestic Refrigeration Fires

The reason for the severity of these fridge-freezer fires can be attributed to a combination of components that can fail and act as an ignition source, located in close proximity to an extensive source of flammable plastics and insulation material which can burn readily and spread the fire, producing very high heat release rates. Such incidents have highlighted the vulnerability of modern construction methods and have produced some of the most serious fires recorded in residential dwellings in the UK.

8.6 Measures for Reducing the Risk

There is also evidence to suggest that severity of refrigeration fires in Great Britain is significantly higher than in the USA. Based on information obtained from domestic refrigeration fire investigations, and a comparison between the design and construction of refrigeration appliances used in the UK and USA, a number of design measures have been suggested which could be used by manufacturers to significantly reduce the risk of fire e.g. putting a simple metal/non-combustible or fire retardant covering at the back of fridge and freezer appliances.

8.7 Future Work

8.7.1 Other types of white goods appliance

The work could now be extended to examine failure modes and fire spread mechanism for the other types of white goods appliances
Statistics often do not provide any reality of the seriousness of the incidents, merely a running total of numbers of failures. In the period from the 1990s the 2000/s, fires in washing machines were in excess of 2000 fires per year. This level is currently around 650 per year but the fires attended in the later models, are now including fire spread from the plastic drums, insulation together with the growing plastic composition of panels. Dishwashers and tumble-dryers are following the same trend in more severe fire effects.

8.7.2 Examination of the effect of small holes in appliance backs

The revised British Standard will still allow small holes to be present in the backing material. Further research is required to examine the effect of such penetrations and establish whether they could compromise fire safety performance. The success in specifying flame tests rather than hot wire application will ensure that materials are honestly exposed to the risks that surround them.

8.7.3 Revision of standards and future safety

The growth and ability to produce products constructed of plastics has produced many rewards for both the manufacturing industries and the consumer. There are also growing pressures to produce goods that are environmentally friendly and re-cyclable. The concept of making a component that is unlikely to fail may be a goal when building a space rocket, but when attempting to build a family refrigeration appliance for a minimum cost, the likelihood of a failure is shown by historic investigations into previous fire investigations such as those listed in the thesis. The options available are to continue to attempt to produce components that don't fail, or to assume that a failure may occur and limit the spread of the resulting fire.

Historically, earlier refrigeration models had far less potential to ignite the construction materials surrounding them. This has now changed. It should also be remembered that this appliance is likely to be adjacent to other similarly constructed kitchen appliances and that fire spread is a common consequence. Since it is the manufacturers that effectively decide their own safety measures perhaps the revision of standards is a priority.

Consequential testing has been discussed in order to establish possible future issues with products and at least one major American manufacturer carries out 'forced failure testing' on its appliances. A concept that by producing a failure in every component, the resulting consequences from fire, electrical and mechanical involvement will be highlighted and may allow a greater understanding of how to mitigate it.

REFERENCES

Althouse A. et al. (1982*) Modern Refrigeration and Air Conditioning*. The Goodheart-Willcox co. Inc. US. ISBN 0-87006-340-5

Althouse.A. et al. (2000) *Modern Refrigeration and Air Conditioning*. The Goodheart-Willcox co. Inc. US ISBN 1-56637-724-2

ASRE (1943) *Domestic Refrigeration and Refrigerators Refrigerating data* book 5th Edition American Society of Refrigerating Engineers New York P-341

ANSI/ASHRAE (2001) "*Designation and Safety Classification of Refrigerants" Atlanta GA.* Table p-14 Refrigerant gases table 2.2 made from listed gases.

Beard A. Goelbelbecker S (2007) *Fire Behaviour of Household Appliances towards External Ignition*. EFRA Germany https://flameretardants-online.com/images/itempics/8/8/1/item 18188 pdf 1.pdf _Accessed date 3rd Nov 2019

Beasley M. (2008*) Death by Design. The Monster in My Kitchen* ISFI 2008 International Symposium on Fire Investigation Science and Technology P75- National Association of Fire Investigators

Brabrauskas V. (2003) *Ignition Handbook: Principles and applications to fire safety engineering fire investigation risk management and forensic. Fire Science* Publishers. Washington ISBN 10:0972811133

Brabrauskas V. (2008) Heat Release Rates (Section 3, Chapter 1) SFPE Handbook of Fire Protection Engineering. Quincy MA: SFPE/NFPA

BSI Group (2017) European Standards and The UK BSI Group 389 Chiswick High Road London, W4 4AL United Kingdom. www.bsigroup.com/LocalFiles/en-GB/EUREF.pdf Accessed date 2nd Sept 2019

Chapman L. (2010) *History of the refrigerator: Staying cool throughout the ages*. The *Domelre* – (Domestic Electric Refrigerator) MLA APA Chicago

Chicago tribune (1929) *Officials debates danger of gas in refrigerators*. USA 1st June 1929 https://www.newspapers.com/newspage/355204158/ Accessed date 20th Oct 2019

Cook R. Ide R. (1985) *Principles of Fire Investigation*. IFE UK ISBN 0:903345 07 2

Daily Illini (1929) *Chicago officials face case of 4 deaths escaping gas from electric fridge*. Student university newspaper Illinois 2nd July 1929 P-1 039-DIL-1929-07-02-001-SINGLE.PDF

Daily Illini (1929) *Dr Kegel reports findings on refrigeration 5 of the leading manufacturers use methyl chloride gas in cooling units.* Student university newspaper Illinois *3rd July 1929 P-1-2. 039-DIL-1929-07-03-001-SINGLE%20(1).PDF Assessed date 20th Aug 2014*

Daily Illini (1929) *Jury orders halts installing of gas ice machines.* Student university newspaper Illinois 4th July 1929 P-1. 039-DIL-1929-07-11-001-SINGLE.PDF Assessed date 20th Aug 2014

Daily Illini (1929) *Officials report on gas investigation*. Student university newspaper Illinois 11th July 1929 P-2 039-DIL-1929-07-04-001-SINGLE%20(1).PDF Assessed date 20th Aug 2014

Daily Illini (1929) *Methyl chloride gas cause death of 3 verdict*. Student university newspaper 27th July 1929 P-2 039-DIL-1929-07-23-001-SINGLE.PDF Assessed date 20th Aug 2014

Dannen, G. (1997). *The Einstein-Szilard Refrigerators*. Scientific American, *276*(1), 90-95. http://www.jstor.org/stable/24993569 Accessed date 4th Oct 2019

DeHaan J. (1983) *Kirks Fire Investigation* 2nd Edition J Wiley & Sons. US ISBN 0-471-09279-7

DeHaan J. (2002) *Kirks Fire Investigation* 5th Edition Brady Fire US ISBN 0-13-060458-5

Drysdale D. (1999*) An Introduction to Fire Dynamics 2nd Edition* Wiley & Sons P-173 Burning of fuels., P224 Ignition. ISBN 0471972916

Edelmann, F. (2016) (31: viii*): The life and legacy of Thomas Midgley* Jr. Papers and Proceedings of the Royal Society of Tasmania 150(1): P-45–49.

Embraco (2019) *Technical Information Refrigeration Compressors*
2 Compressor Application Manual - EMBRACO - PDF Catalogue
https://pdf.directindustry.com › EMBRACO Accessed date 14th Oct 19

Environmental Agency UK. (2012) *Flammability of fridge insulation foam produced with a hydrocarbon blowing agent*. UK LIT 7627 2

R.R. Fullwood and R.E. Hall, (1988) Probabilistic risk assessment in the nuclear power industry. Pergamon Press, UK, 1988

Giunta J (2006) *Thomas Midgley, JR., and the Invention of Chlorofluorocarbon Refrigerants: It aint necessarily so.* Le Moyne College Bull. Hist. Chem., VOLUME 31, Number 2 (2006) P66-74

Glover J. (2018) Expert Evidence 27th November 2018 P.D.F Grenfell Tower Public Enquiry. www.grenfelltowerinquiry.org.uk/hearings/expert-evidence-dr-glover

Gov.UK 2012*. CE Marking guidance*. From Dept of Business, Energy and Industrial Strategy (BEIS) Oct 2012.

Hagan R. (1994*) Plastics. Plastics FAQs* American Chemicals Council infohouse.p2ric.org/ref/11/10437.pdf P- 4-8. US

Hall J. (2009*) Home Structure Fires Involving Kitchen Equipment Other Than Cooking Equipment*. (2003-2006). National Fire Protection Association Fire Analysis and Research Division. Quincy MA

Hall J. (2012) *Home Structure Fires by Equipment Involved In Ignition*. (2006-2010) National Fire Protection Association Fire Analysis and Research Division. Quincy MA https://www.nfpa.org/News-and-Research/Data-research-and-tools/ARCHIVED/Fire-statistics/Fire-causes/Appliances-and-equipment/Home-structure-fires-involving-kitchen-equipment.Accessed date 3rd Oct 2018

Hietaniemi J. et al (2001) *Burning of Electrical Household Appliances*: An Experimental Study VTT Technical Research Centre Sweden ISBN 951-38-5802-2 http://www.inf.vtt.fi/pdf/

Hertzmann P. (2016*) The Refrigerator Revolution*. Food and Revolution Dublin Gastronomy Symposium P-5 Dublin

Home Office (2012) https://www.gov.uk › government › collections › fire-statistics-Great-Britain Accessed date 3rd Nov 2019

Home Office. (2017) *Publishing Incident Recording System, data on the fire and rescue service at an Incident Level*: Domestic Appliance Fires Dataset Guidance, Home Office, OGL, UK, 2017. https://www.gov.uk/government/statistical-data-sets/fire-statistics-data tables #incident-level-datasets Accessed date 3rd Nov 2019

Home Office UK (2019). *Fire Statistics table no 0605 2010-2018* Home Office Gov.UK

Home Office *UK 2016 (DS-2) incident level domestic appliance fires data set* Gov.UK

Kemet (2012) *Capacitors for A.C. motor applications*. http://www.kemet.com/Lists/ProductCatalog/Attachments/158/F9000_GenInfo_MotorCaps.pdf

Kahn M. *Multilayer ceramic capacitors.* Materials and manufacture. AVX Corporation SC. www.avx.com 58896 MLC-Materials & Manuf.pdf

Kegel A.et al (1929) *Methyl chloride poisoning from domestic refrigerators*. *JAMA.* 1929;93(5):353-358. doi:10.1001/jama.1929.02710050007003

Kelvinator. (1926*) Kelvinator, the oldest domestic electric refrigeration*. Electric Refrigeration Corporation. Kelvinator Division. Detroit MI ark:/13960/t5w67n72x.

Kim D. et al. (1994) *Electrical breakdown of the positive temperature coefficient of resistivity barium titanate ceramics*. J Mater Res, vol 11, no 8 Aug 1996

LFB (2005) *Fire Investigation.* Policy document 399. June 205 LFB p:2-3

LFB (2015) *Mobilisation* Policy document 412. Oct 2015. P:7-9

LFB (2011) Fatal Fire Investigation Report Sonia Gardens NW10 LFB Fire incident no 155184111 20/02/12

LFB (2017) (DS-1) *Information Management System* (IMS) Fire Data system 2010- 2015

LFB (2016) *Fires in white goods and product Recalls*: Actions for LFB 2016v (FEP 2572)

LFB (2015), Video footage of fridge-freezer fire tests performed at BRE - https://www.london-fire.gov.uk/news/2015-news/fridge-freezer-delay-putting-lives-at-risk/

NFPA 1033 (2014) *Standard for Professional Fire Investigators* National Fire Protection Association 2014 Edition. (NFPA) Quincy MA ISBN-13: 978-1455907274

NFPA 921 (2004) "definitions" National Fire Protection Association 921Guide for Fire and Explosion Investigations 2004 Edition. (National Fire Protection Association, Quincy MA) p.-21-9-3.3.94 ISBN-10: 9990030685

NFPA 921 (2008) “basic fire science” National Fire Protection Association 921Guide for Fire and Explosion Investigations 2008 Edition. (National Fire Protection Association, Quincy MA) *Chapter 5* P- 18 basic fire science. ISBN 10:0064641228

NFPA 921 (2014) ‘basic fire science” National Fire Protection Association 921Guide for Fire and Explosion Investigations 2014 Edition. (National Fire Protection Association, Quincy MA) *Chapter 5* P- 25 fire tetrahedron ISBN-13: 9781455908509

NFPA 921 (2017) National Fire Protection Association 921Guide for Fire and Explosion Investigations 2017 Edition. (National Fire Protection Association, Quincy MA) ISBN-13: 978-1 45591602-3

Nic Daeid N*. (2018) Grenfell Tower Public Enquiry Phase 1 report* 28th March 2018 University of Dundee. www.grenfelltowerinquiry.org.uk/evidence/professor-niamh-nic-daeids-expert-report

Nimmo K. Vaughn-Davies A. (2012) *Refrigeration Insulation Research*. Bureau Veritas Report LFB/11/615. Fire and Safety Department Report for LFB Fire Investigation.

Nistitani K. and M. Itoh, (2016) *Product innovation in response to environmental standards and competitive advantage*: a hedonic analysis of refrigerators in the Japanese retail market, Journal of Cleaner Production, 113 (2016), 873-883. Japan

NTIS (2005) *Polymer Flammability.* National Technical Information Service (NTIS), Springfield, Virginia 22161. U.S. Department of Transportation Federal Aviation Administration DOT/FAA/AR-05/14

OPDM (2004) *Fire Statistics (UK) 2002-2004*, 3-year average Office of the Deputy Prime Minister.

Polyurethanes (2017*) Refrigeration and freezers* – Polyurethanes ISOPA - European Diisocyanate and Polyol Producers Association. Av. E. Nieuwenhuyse Av. E. Van Nieuwenhuyse Laan (2019) http://polyurethanes.org/en/about-us-isopa Belgium Accessed date 3rd Aug 2019

Rees J (2013) *Refrigeration nation: a history of ice appliances, and enterprise in America.* John Hopkins University Press. ISBN 13: 978-4214-1106-4

Risk Statement (2018) Hotpoint Fridge Freezer model FF175B. www.gov.uk/government/publications/hotpoint-fridge-freezer-ff175b-independent-investigation

Rohr K. (2002) *Appliances and equipment involved in fires.* The U.S. HOME PRODUCT REPORT. (1994-1998). National Fire Protection Association Fire Analysis and Research Division NFPA.ORG

Singh S (2002) *Blowing Agents for Polyurethane Foams 2002* Rapra Technology Limited USA

Smith C. (2005) *Domestic refrigeration and refrigerators in museums Victoria collections* P-1 *https://collections.museumvictoria.com.au/articles/71 Accessed date 3rd May 2019*

South Yorkshire Fire Service (2005) INC no 11727051, 05/05/2005). Sheffield Coroner's Office. UK

Supancic P. and Danzer R. (2005) *Fracture of Electroceramic Components*. Institut für Struktur- und Funktionskeramik, Montanuniversität Leoben, A-8700 www.Researchgate.net

Sweeney K (2018) Hotpoint Fridge Freezer (FF175B) *Summary of Test Results. Report* 103250895LHD-002 Intertek UK. www.gov.uk/government/publications/hotpoint-fridge-freezer-ff175b-independent-investigation

Sweeney K (2018) Hotpoint Fridge Freezer (FF175B) Test Report. Report 103250895MKS-001 Intertek UK.

www.gov.uk/government/publications/hotpoint-fridge-freezer-ff175b-independent-investigation

Times (1929*) Ice Machine Gas Kills 15 in Chicago*," New York Times, July 2, 1929, p- 18.

Times (1929) *Move to Prevent Ice-Box Anxiety*," New York Times, Aug. 1, 1929, p-17.

Times (1957) *Homes with Refrigerators*. The Times London 10 Dec 1957 page 8.

Tyco Electronics (2013) White paper. *Glow wire testing for the appliance industry*. 503-32020 UK Whitegoods (2007) Manufacturers information

Frigidaire. www.ukwhitegoods.co.uk/help/about-the-appliance-industry/manufacturer-information/2900-frigidaire-domestic-appliances

UK Government. (2005) *The General Product Safety Regulation 2005* Statutory Instrument SI 1992/2870 UK

Urbana (1929) 2 dying of poison: blame refrigerator. Urbana Daily Courier Feb 23 1929.P-1.039-TUC 1929-02-23-001-SINGLE.PDF

Urbana (1929*) Further peril by gas fumes*. Urbana Daily Courier July 2 1929.P-10. 039-TUC-1929-07-02-001-SINGLE.PDF

US Energy Information Administration (2009). *Residential Energy Consumption Survey* (RECS) Data, Table HC3.1 Appliances in U.S. Homes

USFA (2008) Fire causes PowerPoint www.ncdoi.com/OSFM/Fire Rescue Commission/Documents/NFA Lesson Plans/IFIFR-U03slides.ppt. Accessed date 23rd Sept 2018

Watkins H. (2008*) Fridge Space: Journeys of the Domestic Refrigerator.* University of British Columbia Thesis.

Xiao R. Y. Zhang, X. Liu and Z. Yuan (2015). *A life-cycle assessment of household refrigerators in China,* Journal of Cleaner Production, 95, 301-310

Yang et al. (2013) outline a methodology which has been employed, in China, to investigate fires caused by a household refrigerator. Research of Trace Analysis and Investigation Method for Refrigerator-caused Fire. Procedia Engineering, 52 (2013) 526-531. China

APPENDIX A

COMMON COMPONENTS IN MODERN REFRIGERATION VCR APPLIANCES

A.1 The Compressor

The compressor is an electrically driven motor (pump) that compresses the refrigerant gas vapour to a high pressure and temperature (superheated) vapour, which can then move into the condenser to transfer heat to the surrounding environment.

A.2 Compressor wiring harness

The compressor wiring harness comprises the wiring system from the electrical outlet to the compressor switch, the capacitor and the wiring from the compressor switch to the internal wiring loom inside the appliance. An example taken from a disposed appliance, Figure A.1 illustrates a typical electrical installation diagram of a wiring harness.

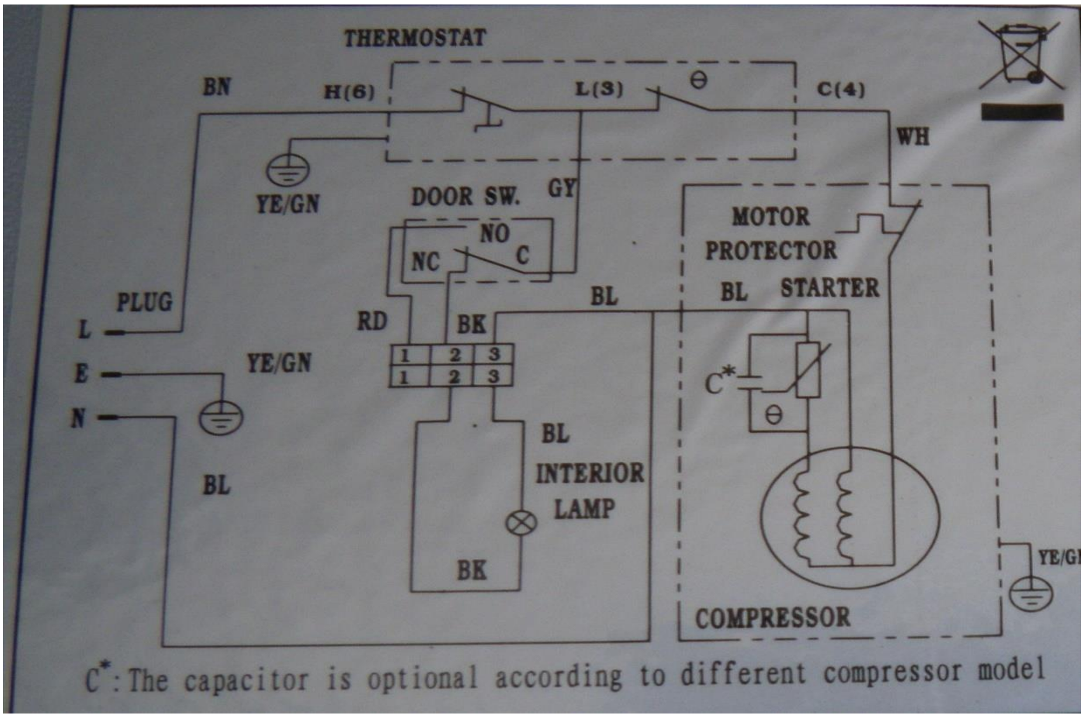


Figure A.1 A wiring diagram from a fridge/freezer (Amenity site 03/2012)

A.3 Compressor starter or relay switch.

The starter switch or relay is used to start the operation of the compressor motor. Earlier models of fridge/freezer employ a starter relay attached to the compressor. This allows current to pass to the start windings of the compressor. Once the compressor starts to run, the relay opens, cutting off the current, and the compressor then functions independently. More modern designs use a starter switch. The starter switch consists of a PTCR (positive temperature coefficient of resistivity also commonly called PTC) ceramic "pill" housed in a plastic body containing the electrical connections. The barium titanate ceramic material used in the pill undergoes a sharp transition from a low resistance (semiconductor) to a high resistance (insulator) state above a critical temperature (typically around 120°C) effectively preventing current flow to the start windings of the compressor. Hence the pill functions as a temperature switch.

A.4 Compressor overload protection device (OLP)

A safety cut-out, resettable switch, providing protection from the occurrence of either current overload or excessive heat within the compressor. Normally a bi-metallic disc opens to break the contact points.

A.5 Compressor capacitor

A capacitor is a device capable of storing and releasing an electrical charge. Its function is normally to either provide a start or run facility which smooths out electrical supply imbalances to the compressor and modifies the phase of the current supplied to the compressor motor windings to create a rotating magnetic field to help start or run the motor.

A.6 Compressor housing

A compartment containing the compressor and its supporting components. It is usually located at the base to the rear of the appliance.

A.7 Refrigerator electrical supply cable and plug

The electrical cable connecting the appliance from the electrical outlet to the refrigerator. Commonly from the socket outlet to the compressor switch.

A.8 Defrost thermostat

A thermostat that energises (opens) the heater circuit when the evaporator temperature rises above a pre-set level thereby preventing excessive heating in the freezer compartment.

A.9 Defrost timer switch (mechanical or electronic)

An electrically energised switch that allows the refrigerator to follow a defrost cycle by switching off/on the compressor and switching on/off heating elements to remove the build-up of frost and ice.

A.10 Freezer evaporator fan

An electrically powered fan that increases the airflow over the heat exchange surface of evaporators.

A.11 Drain heater

An electrically operated cable providing heat during the defrost cycle to allow frost or ice in the drain channel to melt and flow.

A.12 Condenser coil and tubing

The metal tubing assembly located on the outside of appliance receives hot, high pressure refrigerant gas from the compressor and cools it (by transferring heat to the surrounding environment) so that it returns to its liquid state.

A.13 Evaporator coil and tubing

The evaporator coil assembly is located within the appliance and is fed with a very cold liquid/vapour mist, after liquid from the condenser has passed through the expansion valve. In the evaporator coil this refrigerant mist evaporates absorbing heat from the air in the interior of the appliance.

A.14 Control Board – PCB

In appliances now operating with electronic components, rather than mechanical components, the use of printed circuit boards (PCBs) allows the operation of controlled electrically energised functions. A common position of the main control board is often beneath the lid cover at the top of the appliance.

APPENDIX B

FIRE SCIENCE

B.1 Fire definition

Fire is an oxidation process, which is a chemical reaction resulting in the evolution of light and heat in varying intensities (NFPA 921).

B.2 Combustion - The Fire Triangle/Tetrahedron.

A common description of fire is to consider the three components required for combustion to occur. The combustion reaction can be characterised as:

- The fuel
- The oxidising agent
- The heat

These three components are commonly characterised by a geometric, three-sided form called the fire triangle. (Gorbett, 2011). Removal of any one of these components will cause a fire to be extinguished. The concept has also been extended to give the so called "Fire Tetrahedron", so as to include the additional component of "chemical chain reaction". Such chemical chain reactions must also be sustained if combustion is to occur (NFPA 921 2014). Traditionally, to extinguish a fire you need to remove one side of the triangle. Halon adds a fourth dimension to firefighting by breaking the chain reaction.

B.3 Pyrolysis

Flaming combustion is a gas phase phenomenon. For a solid or liquid to burn it must therefore first be converted into a gas. In solids, a chemical decomposition known as pyrolysis is required to produce products that are able to volatilize from the surface as a gas to burn in the flame. Pyrolysis is the process in which material is broken down or decomposes into simpler molecular compounds by heat alone. Pyrolysis often precedes combustion (*NFPA 921 2017*)

B.4 Polymers

Many common solid fuel sources involved in building fires (e.g. wood, plastics) are polymers. Polymers are made from long chains of repeated units of molecules (monomers). The degree of cross-linking between the polymer chains can significantly modify the properties of the polymer. For example, in the case of expanded polyurethane - in flexible foams the level of cross-linking between different chains is low, but by increasing it a rigid polyurethane foam can be produced.

Man-made polymers can be classified into two groups – thermoplastic or thermosetting. Examples of thermoplastic polymers are polyethylene (PE), polypropylene, polymethylmethacrylate (PMMA), polystyrene, and polyvinylchloride (PVC). Examples of thermosetting polymers are polyurethane (PU) foams and polyisocyanurate (PIR) foams. Polymers also typically melt when heated, forming drops or pools of molten polymer that can enhance fire spread. (NTIS 2005)
Thermoplastics tend to melt away from a source of ignition, but when ignited may spread a fire by shedding burning drops. The widely used polystyrene foams are thermoplastic and relatively difficult to ignite, as the polymer shrinks away from the heat source. However once ignition is established, there is rapid surface spread of flame with dense smoke production. Polyethylene melts away from flame, but when ignited it tends to burn steadily with a low, relatively smokeless flames and sheds burning droplets. Thermosetting plastic produce a rigid char, which provides may be capable of smouldering either on its own or in contact with another material, which provides pilot ignition. In some cases, surface char may form an insulating layer, which has a fire-retardant effect. Some plastics are self-extinguishing unless continuously exposed to an external heat source. In the case of PVC, this must be at a temperature greater than 470°C. In general, many plastics ignite at temperatures between 400°c and 500°c. (Nic Daéid 2004)

B.5 Burning of Fuels

The rate of burning (energy release) from the fire is the most important factor characterising its behaviour (*Drysdale 1999)*. In a solid or liquid fire, the rate of burning is linked to the rate of heat transfer from the flame to the fuel surface. The orientation of the fuel surface will also have a strong influence on the burning behaviour and rate of flame spread. Thus, a flame on a combustible vertical surface will directly impinge on the unburnt fuel surface above, causing it to heat-up and spread (upwards) far more rapidly than for a similar material positioned horizontally.

B. Ignition

- Ignition is the heating of a substance to the point of combustion or chemical change. It is the process of initiating self-sustained combustion. (NFPA 921 2008).
- Ignition temperature is the minimum temperature at which a substance will ignite under specific test conditions.
- Piloted ignition is the Ignition of combustible gases or vapours by a secondary source of energy or “pilot” such as an electrical spark or an independent flame.
- Flash-point is the lowest temperature of a liquid, as determined by specific laboratory tests, at which sufficient vapours are given off to form an ignitable mixture across its surface.

- Fire-point is the lowest temperature at which the vapour of the fuel will ignite and sustain a continuous flame.

The criteria for ignition are usually defined in terms of a critical radiant heat flux (kW/m^2) or critical surface temperature (°C). Typically, sustained flaming requires an exposure duration of 30 s or more (Drysdale 1999). The factors affecting ignition are:

- Thermal inertia of material
- Ignition Temperature
- Heat of combustion
- Critical mass flux of volatiles at the fire-point
- Heat transfer within the fuel

The possible sources of ignition for a general domestic fire include

- Flames
- Hot surfaces
- Smoking materials
- Lighters and matches
- Open fires
- Direct fired space heating including boilers
- Gas and electric heaters
- Lighting
- Electrical appliances and equipment faults
- Electrical intake, consumer units and internal wiring faults
- Spontaneous combustion
- Self-heating
- Sun's rays
- Batteries
- Portable devices such as chargers.
- Chemical reaction between certain chemicals

(USFA 2010)

B.7 Electrical ignition source

An electrical ignition source is defined as a fault, damage or malfunction of an electrical system that creates unwanted heat to ignite susceptible fuels. The most frequent causes of fires in electric devices and wiring are overloading, short circuits, battery faults, electric sparks and resistance faults from worn contacts. Abnormal electrical activity may produce characteristic damage that may be recognised on conductors, contacts terminals and wiring. (NFPA 921 2017).

B.8 Flame spread

The process by which flame front acts as source of heat raising the temperature of the fuel ahead of the flame and as a source of pilot ignition.

The significant factors affecting the rate of flame spread over combustible solids include (Dietenberger, 2016):

- The density of the material involved
- The flammability of the material
- The moisture content of the material involved
- The surface temperature at ignition
- Thermal conductivity of the material
- The available oxygen and airflow
- Geometry (slope) of the surface

APPENDIX C

FIRE HAZARD TESTS USED FOR DOMESTIC APPLIANCES

C.1 International Standards

International standards are developed by the International Organisation for Standard (ISO) and International Electrotechnical Commission (IEC) organisations

Electrical appliances including household refrigerators, washing machines, dishwashers and tumble dryers are covered by BS EN (ISO) 60335-1 “Household and similar appliances – Safety – Part 1”, Section 30,

The most important standardised fire tests applied to household electrical appliances - end products and materials are:

- Flammability Tests (IEC 60695-11-10 and IEC 60695-11-20)
- Glowing Wire Tests (IEC 60695-2-10 to 13)
- Needle Flame Tests (IEC 60695-11-5)

C.2 Flammability Tests (IEC 60695-11-10)

These tests are based on UL-94 Horizontal Burning (HB) and Vertical Burning (V). In the 50 W horizontal flame test (based on UL 94 HB) a 50 W Bunsen burner flame is applied for 30 seconds, at an angle of 45°, to the free end of a horizontal sample (of length 125 mm) of the test material (with the other end being held in a clamp) and which is orientated at an angle of 45° (see Figure 2.1.).

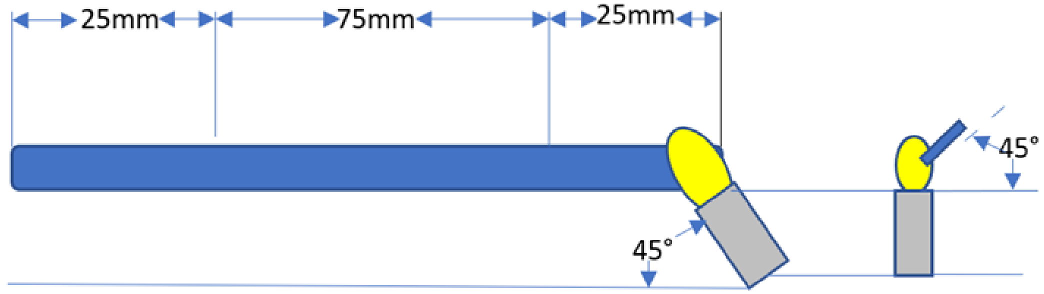


Figure C.1 Horizontal flame test arrangement based on UL 94HB.

The time for the flame front to propagate from the 25 mm mark to the 100 mm mark is observed, and the damaged length, *L*, is taken to be 75 mm. If the flame fails to reach the 100 mm mark then *t* is the elapsed time and *L* is the distance between the 25 mm mark and the distance where the flame front stopped. Three specimens are tested in total. The linear burning rate for each specimen, *v*, in units of mm/min is then calculated using:

$$v = \left(\frac{L}{t}\right) \times \left(\frac{60\ s}{min}\right) \qquad \text{Eqn C.1}$$

A material is then classified as being HB if it conforms to one of the following criteria:

a) It does not burn with a flame after removal of the ignition source;
b) The flame front does not pass the 100 mm mark;

c) If the flame front passes the 100 mm mark,
   and $v \leq 40$ mm/min for 3 mm ≤ specimen thickness ≤ 13 mm
   or $v \leq 75$ mm/min for specimen thickness < 3 mm

HB40 - If the flame front passes the 100 mm mark and v ≤ 40 mm/min
HB75 - If the flame front passes the 100 mm mark and v ≤ 75 mm/min

In the 50 W vertical flame test (based on UL 94 V) a vertical 50 W Bunsen burner flame is applied for 10 seconds to the bottom end of a vertical specimen of the test material (of length 125 mm), with the top end being held in a clamp. The lower end of the specimen is positioned 300 mm above a horizontal cotton pad/tissue (see Figure C.2).

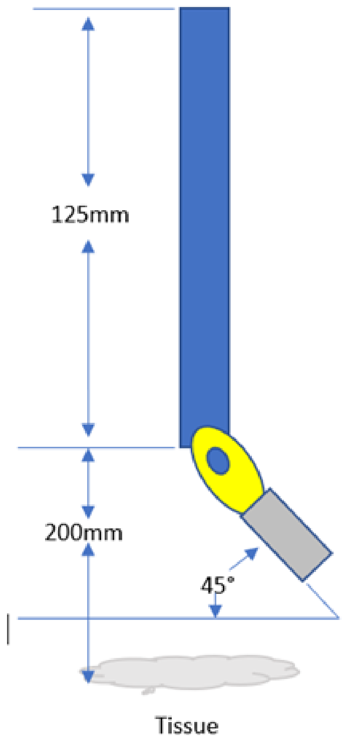


Figure C.2 Vertical flame test arrangement based on UL 94V.

If the specimen produces molten drops, the burner flame should be tilted at an angle of up to 45°, to allow them to reach the tissue/cotton pad. After 10 seconds the flame is withdrawn and the after-flame time t_1 observed. When flaming ceases the burner flame is then re-introduced for a further 10 seconds, and the after-flame time t_2 and afterglow time t_3 observed. During the test it is also noted if the flame front “burned to the holding clamp” and whether any particles or drips fell from the specimen (and if so whether the cotton pad was then ignited). The test is then repeated for two sets of five specimens.

The total after flame time, t_f, is then calculated for each set of 5 test specimens using:

$$t_f = \sum_{i=1}^{5} (t_{1,i} + t_{2,i}) \qquad \text{Eqn C.2}$$

The material is then classified as being either V-0, V-1, or V-2 in accordance with the criteria set out in table C.1. (UL 94 1993)

Table C.1 Material classification criteria for vertical flame tests

Criteria	Materials Classification		
	V-0	**V-1**	**V-2**
Individual test specimen after flame times (t_1, t_2)	≤ 10 s	≤ 30 s	≤ 30 s
Total after flame time for set of five specimens (t_f)	≤ 50 s	≤ 250 s	≤ 250 s
After flame time + afterglow time after 2nd flame application (t_2 + t_3)	≤ 30 s	≤ 60 s	≤ 60 s
Any specimen "burned to the holding clamp"?	No	No	No
Cotton pad ignited by flaming particles of drops?	No	No	Yes

- V-0 Vertical Burn: The 20mm flame is applied for ten seconds to the base of each of five vertical test bars. Burning stops within 10 seconds for the first flame application and flames plus after glow within 30 seconds after the second flame applications. The total burn time for all tests shall not exceed 50 seconds. Specimens shall not burn to the upper clamp and shall not generate burning drips.

- V-1 Vertical Burn: As V0 but burning shall stops within 30 seconds for the first application and flames plus after glow within 60 seconds after the second application. The total burn time for all tests shall not exceed 250 seconds. Specimens shall not burn to the upper clamp and shall not generate burning drips.
- V-2 Vertical Burn: As for V2 except that the generation of burning drips is allowed.

The plastic evaporation tray located on top of the compressor makes any burning droplets an undesirable feature.

C.3 Glowing Wires Tests (IEC 60695-2-10 to 13)

Glow wire tests are used to determine the flammability and ignitability of materials and end products such as domestic appliances. In glowing wire tests a glowing wire with an adjustable temperature is pressed into the surface of the sample being tested for a period of 30 seconds (Figure C.3)

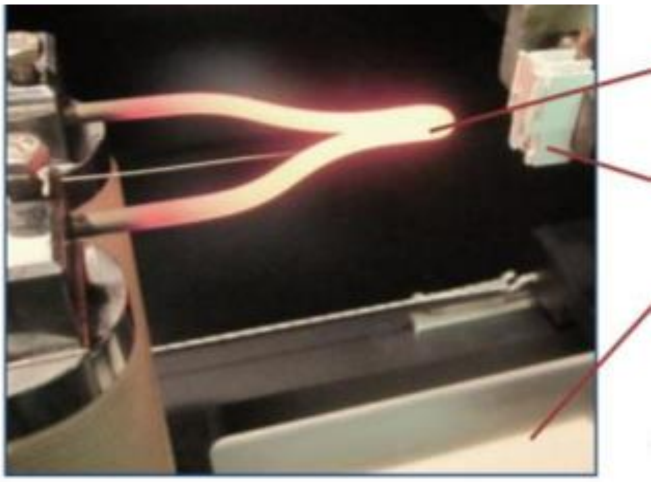


Figure C.3 The glow wire test apparatus used for IEC 60695-2-11
(Tyco Electronics 2013)

The test procedures are specified in:

IEC 60695-2-10 Glow wire Apparatus and common test procedure
IEC 60695-2-11 Glow-wire Flammability test method for end-products Glow Wire Test (GWT)
IEC 60695-2-12 Glow-wire Flammability test method for materials Glow Wire Flammability Index (GWFI)
IEC 60695-2-13 Glow-wire Ignitability test method for materials Glow Wire Index Test (GWIT)

The GWT test applies the glowing wire to the finished component (used in the end product). To pass it must not ignite at 750°C, and any flame must self-extinguish within 2 seconds of the glowing wire being removed. No flaming drips are permitted.

The GWFI test uses the glowing wire to characterise a materials extinguishment behaviour once a flame is removed. To pass the material is permitted to ignite at 850°C, but then must self-extinguish within 30 seconds of the glowing wire being removed from the surface.

The GWIT test uses the glowing wire to characterise a materials ignition behaviour. To pass the material must not ignite at 775°C and any flame must self-extinguish within 5 seconds of the glowing wire being removed in 3 successive tests. No flaming drips are permitted. Alternatively, a range of glowing wire temperatures can be tested, with the ignitability temperature (GWIT) being taken as 25°C higher than the highest temperature that does not lead to ignition (i.e. with a flaming combustion time > 5 s) in three successive tests.

The table C.2 shows the variations of temperatures specified for glow wire testing, dependant on the equipment/components use.

Table C.2 Guidance for glow-wire test. (BS EN 60695-2-11: 2001)

Kind of equipment	Parts made of insulation material	
	Parts in contact with, or retaining in position, current-carrying parts	Enclosures and covers not retaining current-carrying parts in position
Equipment for attended use	650 °C	650 °C
Equipment for unattended use but under less stringent conditions	750 °C	750 °C
Equipment for attended use but under more stringent conditions	750 °C	750 °C
Equipment for unattended use continuously loaded	850 °C	850 °C
Equipment for unattended use continuously loaded but under more stringent conditions	960 °C	960 °C
Fixed accessories in installation	750 °C	650 °C
Equipment to be used near the central supply point of a building	960 °C	750 °C
To ensure a minimum level of resistance to ignition of, and/or spread of fire by, parts liable to contribute to a fire hazard, and which are not subjected to other tests in this respect (in order to eliminate highly combustible material)	550 °C	550 °C

C.4 Needle Flame Tests (IEC 60695-11-5)

The needle flame test is used to simulate the effect of a small flame that may arise due to a fault. For electrical appliances a modified version of the needle flame test is used (BS 60335-1 Annex E – describe the modifications).

In the (modified) test, the needle flame test apparatus consists of a 0.5 mm internal diameter burner tube, with a 0.9 mm external diameter to produce the 12mm needle flame. (figure C.4.) The resulting needle flame is applied to a vertical or horizontal edge of the test specimen (if possible 10 mm from the corner), for a specified time (30 s in the case of an electrical appliance). Tissue paper is positioned 200 m below where the needle flame is applied to the sample. If the test specimen drips molten or flaming material the needle flame may be applied at an angle of 45° from the vertical. The modified test is first performed on one specimen. If this specimen fails, the test may then be repeated on two additional specimens, both of which must pass the test. In case of ignition the duration of burning (time interval from flame being removed until specimen flame is extinguished and no longer glowing) is measured and recorded.

The specimen is considered to have passed the needle flame test if:

a. There is no flaming or glowing of the test specimen and the tissue paper is not ignited
b. Flames or glowing of the test specimen extinguish within 30 s (or 15 s for PCBs) after removal of the burner flame and the tissue paper is not ignited

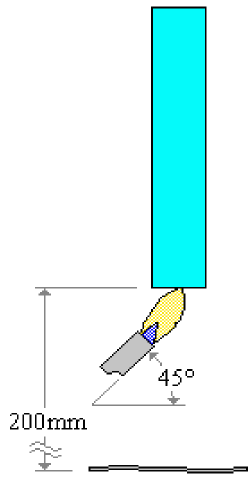


Figure C.4 The Needle Flame Test

APPENDIX D

LONDON FIRE BRIGADE FIRE INVESTIGATION PROTOCOL

D.1 London Fire Brigade (LFB) Fire Investigation

London Fire Brigade (LFB) attends around 10% of all the fires in the UK and around 20% of the recorded appliance fires. LFB first setup a dedicated fire investigation team in 1983. Since that time specialist fire investigation officers have been available to assist the incident commander in determining the origin and cause of a fire. By their very nature LFB fire investigators tend to attend the most significant and severe fire incidents. They also have a number of criteria that mandate their attendance at a fire incident, including any fire involving an injury or fatality or where the cause is unknown.

D.2 LFB Fire Investigation Attendance Criteria

An LFB fire investigation unit will be informed immediately and attend if an incident occurs with the following criteria:
Pre-determined attendance:

- 4 Pump fires, and above
- Persons reported fire.
- Fire-fighter emergency.
- Fatalities at fires.
- To a possible re-kindling from a previous Brigade attendance

Requested attendance – a Fire investigation unit (FIU) is to be requested:

- If the Incident Commander (IC) cannot determine the cause of a primary fire.
- For any serious injury to any member of the public.

Fire investigation is informed of:

- Explosions
- On request for an ambulance from an incident where a fire related injury has occurred to a members of the public (Mop).
- If Incident Commander (IC's) are refused entry to an incident for the purposes of fire investigation, they must request the attendance of an FIU.
- An FIU may be requested to contact the OIC at any incident when there is a requirement for support or advice at a fire scene.
- OIC's should not take samples for fire investigation without the attendance of a FIU.

(Note, The Fire and Rescue Services Act 2004 gave power of entry and power to take samples for obtaining information and investigating fires, to authorised persons.)

- An OIC does not need to request an FIU if there is evidence that a fire is deliberate and assistance is not needed to determine the cause. The IC should request the attendance of the police for fire investigation and complete the report and recording form 1 (RRF 1). (Ref. LFB Policy 412 2015)

D.3 London Fire Brigade (LFB) Fire Investigation

London Fire Brigade (LFB) attends around 10% of all the fires in the UK and around 20% of the recorded appliance fires. Since 1983, specialist fire investigation officers have been available to assist the incident commander in determining the origin and cause of a fire. Investigators tend to attend the most significant and severe fire incidents. They also have a number of criteria that mandate their attendance at a fire incident, including any fire involving an injury or fatality or where the cause is unknown.

APPENDIX E

RESEARCH DATA

E.1 Research Data from recycling yards.

Permission was obtained to be able to attend a number of Council Amenity sites to examine refrigeration appliances prior to disposal. This process continued throughout the research and was carried out, often between fire calls and between shifts.

It was not always possible to remove samples from appliances, only to photograph and exam on site. It was possible to remove selected starter switch's which were photographed labelled and placed in secure bags. Each listed appliance was numbered consecutively from number one and a label was prepared for every sample with (listed as the Ref no) the date, yard, serial number of appliances, make and model (where found) were recorded. All were photographed and the data placed on CDs. The age was identified where possible from manufacturers or serial numbers codes. A number of the switches were then internally examined and photographed. The comments relate to either the specific make, identification numbers or specific observations when removed.

This Appendix lists the appliances in makers order, with details of model, serial number and type of appliance where or if detailed. (fridge, fridge/freezer or freezer), whether the appliance was fitted with a PTC switch. Age if identifiable, a reference number and comments if required.

On many occasions only visual observations were made of certain appliances, such as those already partially dismantled or missing components, on occasions food had been left in compartments and further disturbance would have produced a health risk.

Through the recording of details from fires over previous years, LFB fire investigation reports has provided access to the specific details of many case histories for incidents involving domestic refrigerators. Many of the incidents have resulted in samples being removed and examined by forensic scientists. By employing the methodology described in Chapter 3, the information collected from the scene of fire investigations involving domestic refrigeration appliances over the past decade, has been used here (see Chapters 5 and 6) to identify possible ignition and fire spread mechanisms occurring in fridge and freezer fires. The example from Chapter 5.4, Page 103, of the defrost switch failure was a direct consequence of visiting and recording details from a discarded appliance.

Table E. 1 Starter switch and appliance observations at Recycling yards.

PTC							
Make	**Model**	**Ser no**	**Type**	**PTC**	**Age**	**Ref**	**Comments**
Ariston	ERF312XL	012142043	Fridge/Freezer	Yes		198	PTC Klixon type
Ariston	MP140/UK1	47D07530020	Fridge	No		249	Embraco switch
Asko	KN 8526		Fridge/Freezer	No		42	Twin Compressors
Atlant	KSH 216-01	606083149	Fridge/Freezer	Yes		237	PTC
Atlant	***FS	70490000005073	Fridge	Yes		323	PTC Aspera A97
Baumatic	SL160 Built in	20001920088	Fridge	Yes		245	PTC White Danfoss + Fan
Beko	LN221	HY102215	Fridge	Yes		107	PTC MSDA3
Beko	FN240	001019390101	Fridge/Freezer	Yes	05/01	113	PTC MSDA3
Beko	NF741	ST106086	Fridge/Freezer			12	To check
Beko	FF6126	4226670700	Fridge/Freezer	Yes		129	PTC B1M7
Beko	CQ970	42 22768600	fridge/ freezer	yes		14	PTC white 87A8
Beko	CS460FFS	001014660701	Fridge/Freezer	Yes		160	PTC 82F
Beko	NC781	42 22741800	Fridge/Freezer	Yes		179	PTC BBD7
Beko	FL610	T9101805	Fridge	No		18	
Beko	BX170	SP113984	Fridge	No		191	Klixon type
Beko	FN 245	LX121252	Fridge/Freezer	Yes		200	PTC MSDA3
Beko	ZC130	0112149211	Freezer	Yes		207	PTC MRKK MM8

PTC							
Make	**Model**	**Ser no**	**Type**	**PTC**	**Age**	**Ref**	**Comments**
Beko	5125	MN103401	Fridge/Freezer	Yes		212	PTC MSDA3
Beko	FN240	00/024570101	Fridge/Freezer	Yes		26	PTC A519
Beko	FR 621	VT 107178	Fridge	No		269	
Beko	NC751	MW107162	Fridge/Freezer	Yes		292	PTC B1D7
Beko	FN240	99/422041201	Fridge Freezer	Yes		31	PTC MSDA3
Beko	NC 761	42 22742100	Fridge/Freezer	Yes		337	PTC B8G7
Beko	ZN 230	42-22767300	Freezer	Yes		345	PTC B1M7 + START CAP
Beko	BZ 602	LU106393	Freezer	Yes		44	PTC MSDA3
Beko	ND69NAEM	DFDEO220043251238	Fridge/Freezer	Yes		64	Brought by DC
Beko	BZ602	GU103867	Freezer	Yes		75	PTC MSDA3
Beko	FN240	LY118200	Fridge/Freezer	Yes		80	PTC B709
Beko	ZF430	001040720301	Fridge/Freezer	Yes		83	PTC A3L9
Blomberg	CFFN 270	ME613401	Fridge/Freezer	Yes		164	PTC Black Danfoss
Blomberg	FFN 4229	LM 243191	Fridge/Freezer	No		298	
Blomberg	FFN 6248	LG621677	Fridge/Freezer	Yes		77	PTC Black Danfoss Severe
Blomburg	S12990UG	994320358	Freezer	Yes	06/99	145	PTC Klixon SAHF9
Blomburg	Cff 215	MG2216155		Yes	07/94	32	PTC A4E4
Blomburg	CFF 289	963132/33	Fridge/Freezer	Yes	06/96	82	PTC A FG6
Bloomberg	BC290B	014830962	fridge/Freezer	Yes	11/01	186	PTC Klixon
Bosch	FD6901	KGE 3433SD/01	Fridge/Freezer	Yes		104	PTC BN88
Bosch	KGS2272/GB05		Fridge/Freezer	Yes	02/98	1	PTC Aspera A038
Bosch	KGS 3272 GS 05	90220960	Fridge/Freezer	Yes		2	PTC Aspera Twin Compressors
Bosch	No Door		Fridge/ freezer	Yes	1996	24	PTC Black Danfoss Part dated 1996
Bosch	KGV2604	90.221.30143	Fridge/Freezer	Yes		243	PTC Mrkk
Bosch	FD8011	000448	Fridge	Yes		254	PTC White Danfoss
Bosch	KGV3104	90221059	Fridge/Freezer	Yes		288	PTC MRKK MM8
Bosch	FD6910	0705134411	Freezer	Yes		295	PTC Black Danfoss Acid (Shad Thames)

PTC							
Make	**Model**	**Ser no**	**Type**	**PTC**	**Age**	**Ref**	**Comments**
Bosch	KGV 3120GB/01	FD7908/220035	Fridge/Freezer	Yes		305	PTC
Bosch	KGV 24325GB/05	FD8512/010224	Fridge/Freezer	Yes		334	PTC MRKK MM8
Bosch	No Frost		Fridge/Freezer	Yes	06/96	356	PTC Black Danfoss No plate but part dated
Bosch	KTR1670 GB/44	09035009506010 7123	Fridge	Yes	02/99	359	PTC White Danfoss
Brandt	SCA 252AU	03	Fridge	Yes	02/03	110	PTC A72D3
Brandt	C031BWLU	032831656	Fridge/Freezer	Yes		206	PTC
Brandt	TCA150WU	1149001891	Fridge	Yes		260	PTC White Danfoss
Brandt	CO2OFWL U	011430810	Fridge/Freezer	Yes		78	PTC AHC1
Candy	C347	L056686R92	Fridge/Freezer	Yes		148	PTC MM8-581M
Candy	C47	2B000375	Fridge	Yes	03/92	165	PTC LEC
Candy	CCV110FF	39005796010205	Freezer	Yes	06/95	281	PTC MSDA1
Candy	C 2010/9	3901023 9912 0441	Fridge/Freezer	Yes		301	PTC Klixon Type
Candy	CRU 160 UK	853910015312	Built in Fridge	Yes	06/00	304	PTC Aspera With Fan Assy
Candy	CM28/105G B	39007208061016	Fridge/Freezer	Yes	11/97	308	PTC Klixon damaged
Candy	CM30/12PG B	3900722	fridge/ freezer	Yes	09/97	4	PTC Klixon Examined Burgoynes
Candy	DAR 7 034931 006	8901009-487	Built in Fridge	No		43	
Candy	CTA 130R	3900414 3510409	Fridge	No		67	
Creda	86404	M1226743	Fridge/Freezer	Yes		187	PTC Black Danfoss
Creda	86614	22000058	Freezer upright	Yes	34/95	314	PTC Black Danfoss
Daewoo	FR143WH	1E27242099	Fridge	Yes	2003	158	PTC Klixon type
Daewoo	FR 143WH	1E27242099	Fridge	Yes		158	PTC Klixon type
Daewoo	FR142	1E800105	Fridge	Yes		251	PTC Klixon type
Daewoo	FR153SL	5031117400075	Fridge	Yes		296	PTC Klixon type
Daewoo		1E28261965	Fridge	Yes		321	PTC RSIR +Klixon OL

PTC							
Make	**Model**	**Ser no**	**Type**	**PTC**	**Age**	**Ref**	**Comments**
Daewoo	HPL 25YG1-5	2K1202052	Fridge/Freezer	Yes	2004	65	Brought by DC LG cover
De Dietrich	RG 4160 F11	01/7942-53-00	Fridge	No		105	
Diplomat	APM6724	500205016734	Fridge	Yes	01/02	141	PTC A1A2
Diplomat	APM6117	80630150	Fridge	Yes		278	PTC Black Danfoss
Electra			Fridge/Freezer	Yes	09/95	103	PTC E2G5
Electra	EBL5W	22600176	Fridge	Yes		108	PTC Klixon
Electra	EFF98/1	119744015184	Fridge/Freezer	Yes		224	PTC 2019
Electrolux	TR913	342	Fridge/Freezer	Yes		109	PTC Black Danfoss
Electrolux	TR1125A	6260012	Fridge/Freezer	Yes		119	PTC Black Danfoss
Electrolux	ER1620T	24300258	Fridge	Yes	09/92	127	PTC AL92
Electrolux	TR906W	8080094	Fridge/Freezer	Yes		134	PTC Black Danfoss
Electrolux	ER2946B	63500093	Fridge/Freezer	Yes	05/96	143	PTC A6F6
Electrolux	TF431	4440064	Freezer	Yes		215	PTC Black Danfoss (damaged)
Electrolux	TF775A	7500503	Freezer	Yes		242	PTC Black Danfoss
Electrolux	ER1626T	31400010	Fridge	Yes	02/03	248	PTC A16B3
Electrolux	ER 1641T	23910416	Fridge	Yes	05/02	259	PTC A71H2
Electrolux	TR 1070C	216-0188	Fridge/Freezer	Yes		324	PTC Black Danfoss Damaged
Electrolux	TR1240B	109-0088	Fridge Freezer	Yes		341	PTC Black Danfoss Damaged Twin unit 342
Electrolux	TR1240B	109-0088	Fridge/Freezer	Yes		342	PTC Black Danfoss Twin unit 341
Electrolux	1241B	109-2128	Fridge/Freezer	Yes	02/08	343	PTC Black Danfoss Pair of compressors damaged
Electrolux	1241B	109-2128	Fridge/Freezer	Yes	2003	344	PTC Black Danfoss Pair 344 damaged
Electrolux	ER2947B	71100047	Fridge/Freezer	Yes	01/97	349	PTC B4A7
Electrolux	EUU6174	33700244	Integrated Freezer	Yes	07/03	351	PTC A15H3

PTC							
Make	**Model**	**Ser no**	**Type**	**PTC**	**Age**	**Ref**	**Comments**
Electrolux	TF 1041B	151-0364	Freezer	Yes		53	PTC Black Danfoss Examined Burgoynes
Electrolux	RF555A	612-0367	Fridge	Yes		81	PTC Black Danfoss
urotech	SR2100	104240454	Fridge	No		195	
Fisher & Paykel	E522B	MLQ809761	Fridge/Freezer	Yes		294	PTC MRKK MM8
Fridgemaster	MTRL143	200 103130132	Fridge	Yes		102	PTC
Fridgidaire	R1526H	71610533	Fridge	Yes		178	PTC 2019/D
Frigidaire	R1526H	81411523	Fridge	Yes	01/98	137	PTC Klixon
Frigidaire	R1526H	74210624	Fridge	Yes		21	PTC White 2019D
Frigidaire	Elite		Freezer	Yes		22	PTC White Danfoss
Frigidaire	2625 HDS 201	---- 0302	Fridge/Freezer	Yes		313	PTC Black Danfoss Acid Damaged
Frigidaire	8109P	84252511		Yes		48	PTC ATG1
Frigidaire	RG 5201	24810089	Fridge	Yes		50	PTC 7100D3
Hirundo	FH140 EITP	772	Fridge	No		339	
Hitachi	R93BCS	90130532	Fridge/Freezer	Yes		213	PTC Black Danfoss Pair Compressors see 214
Hitachi	R93BCS	90130532	Fridge/Freezer	Yes		214	PTC Black Danfoss Pair Compressors see 213
Homark	02-9970	MA 152286	Fridge/Freezer	No		330	
Hoover	RCM22GB	3900699 7470284	Fridge/Freezer	Yes		142	PTC MSDA1
Hoover	HCA 390K	34000143	Fridge/Freezer	Yes	36/02	303	PTC White Danfoss
Hotpoint	8326P	85294476	Fridge/Freezer	Yes		10	
Hotpoint	8109P	62552847	Fridge	Yes		100	PTC Black Danfoss Given to Danfoss
Hotpoint	8132A	93191163	Fridge	Yes	04/01	106	PTC BG93
Hotpoint	FZ60P	31101307		No		13	
Hotpoint	8751W	23214202	Freezer	No		133	
Hotpoint		L2865116	Fridge	Yes		159	PTC MSDA & Klixon
Hotpoint	RZ01P	35100214	Fridge	Yes		167	PTC MRKK
Hotpoint	8214A	24368578	Fridge	Yes		173	PTC Black Danfoss

PTC							
Make	**Model**	**Ser no**	**Type**	**PTC**	**Age**	**Ref**	**Comments**
Hotpoint	8553W	59560730	Fridge/Freezer	Yes		182	PTC Black Danfoss Duel Compressors
Hotpoint	8553W	59560730	Fridge/Freezer	Yes		183	PTC MRKK See also 182
Hotpoint	Iced Diamond 8553P	58569370	Fridge/Freezer	Yes		201	PTC MRKK MM8 2 compressors see 202
Hotpoint	Iced Diamond 8553P	58569370	Fridge/Freezer	Yes		202	PTC Black Danfoss pair comps See also 201
Hotpoint	RZ63P	42103801	Freezer	Yes		204	PTC
Hotpoint	RL63P	42100827	Fridge	Yes	05/97	205	PTC TI combo
Hotpoint	RFOOP First edition	25102478	Fridge/Freezer	Yes	1995	210	PTC A AN5
Hotpoint	RF60P	21100931	Fridge/Freezer	Yes	06/95	216	PTC APP5
Hotpoint	8553W Iced Diamond	58572191	Fridge/Freezer	Yes		220	PTC Black Danfoss 2 Compressors 221
Hotpoint	8553W Iced Diamond	5872191	Fridge/Freezer	Yes		221	PTC 2 Compressors 220
Hotpoint	8216W Iced Diamond	19845261	Fridge	No		222	
Hotpoint	RL63N Iced Diamond	47104008	Fridge	Yes	09/97	225	PTC TI Combo
Hotpoint	RL78P	94102158	Fridge	Yes	06/01	230	PTC Klixon set
Hotpoint	8312P	95/06826	Fridge	Yes	08/03	231	PTC AL93
Hotpoint	RL64P Iced Diamond	74101914	Fridge	Yes		240	PTC MRKK
Hotpoint	RL63P Iced Diamond	44101295	Fridge	Yes	05/97	241	PTC Klixon Combo
Hotpoint	rc13p	43/00438	Fridge	Yes		25	PTC Klixon A307
Hotpoint	RL64P Iced Diamond	62100844	Fridge	Yes		252	PTC MRKK
Hotpoint	FZ64P Iced Diamond	65100323	Freezer	Yes		253	PTC MRKK
Hotpoint	Ist edition RZ700P	24100981	Freezer	Yes	10/95	271	PTC A KM5
Hotpoint	RL64P	76122853	Fridge	Yes		275	MRKK
Hotpoint	8729P	54420213	Fridge	Yes		284	PTC MRKK MM8

PTC							
Make	**Model**	**Ser no**	**Type**	**PTC**	**Age**	**Ref**	**Comments**
Hotpoint	8126P Iced Diamond	27814356	Fridge	Yes		287	PTC Black Danfoss Damaged
Hotpoint	-	-	Fridge/Freezer	Yes		29	PTC Black Danfoss Examined Burgoynes
Hotpoint	8759P	70590241	Freezer	Yes		291	PTC Black Danfoss Acid
Hotpoint	8120 Iced Diamond	89821078	Fridge	Yes		293	PTC Black Danfoss Acid
Hotpoint	-	-	Fridge/Freezer	No		30	
Hotpoint	RSB 20P	09713571	Fridge	Yes	07/02	302	PTC Aspera
Hotpoint	8126W Iced Diamond	19844030	Fridge	Yes	02/87	306	PTC Black Danfoss Damaged
Hotpoint	FZ90P	22000026	Freezer upright	Yes	09/95	316	PTC AELS
Hotpoint	RF07P	65100661	Fridge/Freezer		04/99	326	PTC Embraco Klixon
Hotpoint	RLA 50S	12100273	Fridge	Yes		332	PTC Aspera
Hotpoint	8214W	67530989	Fridge	Yes		336	PTC Black Danfoss Damaged
Hotpoint	RFA17P	512080009	Fridge/Freezer	Yes	2005	350	PTC White Danfoss
Hotpoint	8332W	02120791	Fridge/Freezer	Yes		354	PTC MM8-581M
Hotpoint	8214P	56383937	Fridge	Yes	2000	361	PTC Black Danfoss
Hotpoint	Iced Diamond		Fridge	No		38	No model no
Hotpoint	8109P	84252511		Yes		46	PTC AN92
Hotpoint	8553W	22201830	Fridge/Freezer	No		51	Pair Compressors Iced Diamond
Hotpoint	R503P	45101886		Yes		59	PTC Klixon
Hotpoint	First Edition	As 140 F2		No		60	
Hotpoint	8129P	83196495	Fridge	Yes		61	PTC AL92
Hotpoint	RF60W	17101244	Fridge/Freezer	Yes	10/93	85	PTC BM93
Hotpoint	160STD.P. (TB)	RS 5218	Fridge	Yes	04/00	93	PTC A3CO Iced Diamond
Husky	Home Chiller	0602263717720 020305519	Bottle cooler	Yes		277	PTC Twin Klixon
Hygena	APL 6610	02 03363	Built in Freezer	No		317	Early Danfoss

PTC							
Make	**Model**	**Ser no**	**Type**	**PTC**	**Age**	**Ref**	**Comments**
IARP	EKO 42	903B25017	Cabinet Fridge	No	06/98	185	
IARP	AB400PV	04CB36218	Fridge display	Yes		86	PTC A1M3
Iceline	FF45/31	NB171303	Fridge/Freezer	Yes		276	PTC Black Danfoss
Iceline	L-476	none	Fridge	Yes		282	PTC Klixon Pair
Iceline	NKF330	22133285	Fridge/Freezer	Yes		289	PTC Black Danfoss Damaged Twin Unit 290
Iceline	NKF330	22133285	Fridge/Freezer	Yes		290	PTC Black Danfoss Damaged Twin Unit 289
Iceline	CF38	1096/1996638	Chest Freezer	Yes	09-5	360	PTC Black Danfoss
Iceline	U79 577			Yes	08/97	57	PTC Klixon Examined Burgoynes
Iceline	R6-40E		Fridge/Freezer	Yes		66	Brought by DC
Iceline			Chest Freezer	Yes	04/92	94	PTC AD82
Ignis	ARL 104/G	CA 944523195	Fridge	Yes		209	PTC 2019/B
Ignis	ARL 100/TG Built in	TR930806296	Fridge	Yes		226	PTC 2019 paired with 233
Ignis	AFE 275/1G Built in	TR 932819171	Freezer	Yes		233	PTC 2019 paired with 226
Indesit	CG1230	006132477	Fridge/Freezer	Yes		144	PTC Klixon + SR273102
Indesit	RG2250	001311073	Fridge/Freezer	Yes		176	PTC Klixon type
Indesit	CF 239NF	212101600	Fridge/Freezer	Yes		219	PTC White Danfoss
Indesit	RG1142.1	107092085	Fridge	Yes		262	PTC White Danfoss
Indesit	GR 1860	609305536	Fridge/freezer	Yes		33	Klixon
Indesit	CG 1305 NF/1	005301298	Fridge/Freezer	Yes		340	PTC White Danfoss
Indesit	CG1230	210113350	Fridge/Freezer	Yes	08/02	352	PTC SR273104 with Klixon ols
Indesit	C239NF	205160275	Fridge/Freezer	Yes		58	PTC White Danfoss
Indesit	2418 M5 G	831	Fridge	No		6	Relay
Indesit	R24	206273380	Fridge/Freezer	Yes	04/02	73	

PTC							
Make	**Model**	**Ser no**	**Type**	**PTC**	**Age**	**Ref**	**Comments**
Indesit	GR1459	47080860000	Fridge	Yes	03/98	99	PTC MSDA1
Juno	KU51531	91017012-02	Built in Fridge	Yes		184	PTC White Aspera No cover found
Kelvinator	KC22/OE	3445300 543 3082	Fridge/Freezer	Yes	09/95	239	PTC A5H5
Kelvinator	KCF 16/11	3901063 9944 0289	Fridge/Freezer	Yes	34/99	320	PTC White Danfoss
Kelvinator	CTL150G	3900472		Yes		54	PTC MSDA1
Kyoto	R506	0110174105	Fridge	Yes	12/99	116	PTC MSDA3 Iceland
Kyoto	DD190	500131002625	Fridge/Freezer	Yes	07/01	197	PTC 07061/Df
Lec	U550WS	7D 032217	Freezer	Yes	12/88	101	PTC Black Danfoss
Lec	T355CW	9C000/28	Fridge/Freezer	Yes	09/99	118	PTC MSDA3
Lec	R505S	7A003941	Fridge	Yes	03/87	123	PTC Metal cage variety
Lec	U/375S	6D003924	Freezer	Yes	12/86	124	PTC Metal cage variety
Lec	T354SL	5D023006	Fridge/Freezer	Yes	12/85	130	PTC Metal cage variety
Lec	U225S	8B007080	Fridge	Yes	06/88	132	PTC Metal cage variety
Lec	R505S	9B004376	Fridge	Yes	06/89	138	PTC Metal cage variety
Lec	T201SL	4A012329	Freezer	Yes	03/84	139	PTC Metal cage variety
Lec	R450CW	9C024461	Fridge	Yes	09/99	153	PTC White Danfoss
Lec	T278WG	5A001769	Fridge/Freezer	Yes	03/95	156	PTC Black Danfoss
LEC	U191SL	3B000518	Freezer	Yes		172	PTC Metal cage variety
Lec	F121SL	5A002762	Chest Freezer	Yes		175	PTC metal cage variety
Lec	T244SL	4D009249	Fridge/Freezer	Yes		177	PTC metal cage variety
Lec	R504 WG	4D 009927	Fridge	Yes		181	PTC Black Danfoss
Lec	R450CW	08025413	Fridge	Yes		189	PTC MSDA1
Lec	R403W	00005229	Fridge	Yes	11/90	199	
Lec	T278WG	4B001933	Fridge/Freezer	Yes		217	PTC Black Danfoss

PTC							
Make	**Model**	**Ser no**	**Type**	**PTC**	**Age**	**Ref**	**Comments**
Lec	R450WS	7B 021484	Fridge	Yes		234	PTC Black Danfoss
Lec	L555WS	8B002037	Fridge	Yes		247	PTC White Danfoss
Lec	R540W	6A007096	Fridge	Yes	10/95	255	PTC A EM5
Lec	T350WS	6D023014	Fridge/Freezer	Yes		258	PTC Black Danfoss
Lec	T435SE	6D 012132	Fridge/freezer	Yes	12/85	27	PTC Metal cage variety
LEC	EL955BW	116689063	Fridge Upright	Yes		286	PTC White Danfoss
Lec	T450WS	6A 003957	Fridge/Freezer	Yes	05/96	319	PTC Black Danfoss
Lec	R550WS	7B003980	Fridge	Yes		331	PTC Black Danfoss
Lec	T6350CW	045757081	Fridge/Freezer	Yes		338	PTC White Danfoss
Lec	R505S	7A 008156	Fridge	Yes	03/87	34	PTC Metal cage Variety
Lec	T1450WS	8A002404	Fridge/Freezer	Yes	04/08	348	PTC Black Danfoss
Lec	RF109	OB 003101	Freezer	Yes	09/00	353	PTC White Danfoss
Lec	CK68P	4B000507	Fridge/Freezer	Yes	09/04	357	PTC Black Danfoss
Lec	R41C	3D002777	Fridge	Yes	06/03	358	PTC Black Danfoss
Lec	T153W	1B008019	Fridge/Freezer	No	07/91	37	
Lec	L113	7A 002545	Freezer	Yes	03/97	45	PTC Black Danfoss
Lec	L153 SL	5c 00793A	Fridge	Yes	09/85	47	PTC Metal cage variety
Lec	L113		Fridge	Yes		49	PTC MSDA1
Lec	U550W	5D 026511	Freezer	Yes	12/95	56	PTC Black Danfoss
Lec	U824W	00 002872	Freezer	Yes	10/90	69	PTC Lec 1300
Lec			Freezer	Yes		72	PTC Black Danfoss
Lec	T454SL	6B 011079	Fridge/Freezer	Yes	06/86	76	PTC Metal cage variety
Lec	LO60S	000487983	Fridge	Yes	08/99	79	PTC White Danfoss
Lec	R250WS	88003360	Fridge	Yes	12/88	87	PTC White Danfoss
Lec	T435SE	70023026	Fridge/Freezer	Yes	12/87	92	PTC Metal cage variety
Lec	LA153 SL	6B003709	Fridge	Yes	06/86	95	PTC Metal cage variety

PTC							
Make	**Model**	**Ser no**	**Type**	**PTC**	**Age**	**Ref**	**Comments**
LG	GR-151SSF	108KR06341	Fridge	Yes		155	PTC Part Klixon + P330MC
LG	GR 151SSF	107 KR01277	Fridge	Yes		16	
LG	GR 15155F	810KR00184	Fridge	Yes		170	PTC Klixon type
Magnet	UR 726/M	8539 10215120	Fridge Built in	Yes		335	PTC 2019/B
Neff	KU 5R 18		Fridge	No		128	
Neff	G4520X1/GB/01	FD6906	Freezer	Yes	06/89	146	PTC Black Danfoss
Neff	195.307.202	FD6901	Fridge	Yes	01/89	147	PTC Black Danfoss Given to Danfoss
Neff	FD 69404	K4540X0GB/01	Fridge Built in	Yes		193	PTC Black Danfoss
Neff	G4511X0GB/101	-	Fridge Built in	Yes		194	PTC Black Danfoss
Neff	ENR 195-307-202	FD6807	Fridge	Yes		328	Black Danfoss Damaged (no cover)
Neff	4740 12 GS	030275556	Freezer	No		89	
Norfrost	G (6) 105DL	3997/2509415	Freezer Chest	Yes	07/97	322	PTC Klixon A5D7
Nova Scotia	F193	3900635 6420016	Fridge/Freezer	Yes		171	PTC Black Danfoss
Oasis	B1RRHSY	9841807180	Water tower	Yes	pre 1998	117	PTC White Danfoss
Ocean	CBH 62/42	964421405	Fridge/Freezer	Yes	10/96	120	PTC White Klixon
Ocean	C828	FE164008	Fridge/Freezer	No		279	AMF Switch
Ocean	APM 6811	954120234	Fridge/Freezer	Yes		28	PTC Black Danfoss
Ocean	FUF --20B	99250149	Freezer	Yes	07/02	68	PTC A7G2
Ocean	APM6811	960620572	Fridge/Freezer	Yes		74	PTC Black Danfoss
Philips	AFB 075/PH	TR 85111204	Freezer	No		40	
Philips	AFB ?		Fridge	No		41	
Philips	AFB713	TR865101183	Freezer	No		7	
Proline	7063	G8017619	Fridge/Freezer	Yes		111	PTC Sealko see also 112
Proline	7063	G8017619	Fridge/Freezer	Yes		112	Fitted with two comps also 111
Proline	FR-388A	050/2322	Fridge	Yes		114	PTC Klixon
Proline	PC223A		Fridge/Freezer	Yes		163	PTC Klixon type
Proline	PCF 36C	55118251	Freezer Chest	Yes	09/95	232	PTC EL92

PTC							
Make	**Model**	**Ser no**	**Type**	**PTC**	**Age**	**Ref**	**Comments**
Proline	PC2/3NF	021330238	Fridge/Freezer	Yes	01/02	285	PTC A35C2
Proline	FS888	0127 11803	Freezer upright	Yes	04/01	315	PTC Klixon
Samsung	SR-L3626BSS	737441AT300146F	Fridge/Freezer	Yes		23	PTC Two-piece Klixon
Scandiluxe	CF136	95013189	Freezer	Yes	12/99	152	PTC KlixonSA1N9
Scandinova	RF 7054 2	91112150	Fridge/Freezer	Yes		121	PTC Black Danfoss see 122 also
Scandinova	RF 7054 2	91112150	Fridge/Freezer	Yes		122	PTC Black Danfoss See also 121
Scandinova	SLE 75U	50512664	Freezer	Yes		246	PTC Black Danfoss
Scandinova	LF 87C	53734130	Fridge	Yes		263	PTC Black Danfoss
Scandinova	UF 82C	62733550	Freezer	Yes	10/96	268	PTC A ED6
Scandinova	FF6745D	74303522	Fridge/Freezer	Yes		273	PTC Black Danfoss twin comps (274)
Scandinova	FF6745D	74303522	Fridge/Freezer	Yes	09/9-	274	PTC Klixon Twin comps (273)
Scandinova	SLF 111	20233586	Fridge	Yes		280	PTC Black Danfoss Damaged
Scandinova	LF110C	64930083	Fridge	Yes		355	PTC Black Danfoss
Scandinova	RF 7054-067	89245576	Fridge/Freezer	Yes		90	PTC Black Danfoss Pair of compressors
Scandinova	RF 7054-067	89245576	Fridge/Freezer	Yes		91	PTC White Danfoss
Scandinovla	FF 67450	92203855	Fridge/Freezer	Yes		15	PTC White Danfoss + Two Compressors
Schreiber	APM6321SX	200145295?	Fridge Built in	Yes		125	PTC White Danfoss
Schreiber	APM6315	975107606	Fridge Built in	Yes		192	PTC Klixon type
Schreiber	APM6121	952604685	Fridge Built in	Yes		244	PTC Unidad with Klixon OL + Fan
Schreiber	APM 6315	943914103	Fridge Built in	Yes	06/94	283	PTC Necchi Damaged
Schreiber	APP6302	20020826601	Fridge Built in		10/01	325	PTC AHB2
Schreiber	App6403	20033707142	Freezer Built in	Yes	35 03	347	PTC White Danfoss

PTC							
Make	**Model**	**Ser no**	**Type**	**PTC**	**Age**	**Ref**	**Comments**
Servis	M7065-6W	20000804725	Fridge/Freezer	Yes	12/99	157	PTC Klixon SAML9
Servis	M7041	20003611216	Fridge	Yes	07/00	236	PTC Aspera
Servis	RF4367E	K20147B06997	Fridge/Freezer	Yes	11/96	250	PTC B5A7
Shreiber	APM6314	45130642	Fridge Built in	Yes		229	PTC Klixon set
Singer	T511/3 (140)	000097 T5	Fridge	No		228	
Smeg	FR 158	305301108	Fridge	Yes		88	PTC White Danfoss
Sunroc	TPV1HS-002	022301657	Water Tower	Yes		307	PTC White Danfoss
System 600	UF617/-1	TR910906160	Freezer Built in	Yes		264	PTC Black Danfoss Damaged PTC to check
System 600	UR615/1	TR 918784811	Fridge	Yes		71	PTC 2019/B 14
TDA	TDF103	031281406	Freezer	Yes		154	PTC QP2-15
Teba	SBU201-08	90107386	Fridge	Yes		19	PTC Klixon
Teba	SBUZ01 -05	90064946	Fridge	Yes		96	PTC Murata
Tecnik	TKR601/2	0701155813	Fridge	Yes		168	PTC White Danfoss
Tecnik	TKR 621/2	001990	Freezer	Yes		169	PTC White Danfoss
Thorn	60485/1	555428	Freezer	No		62	
Thorn EMI	R400614	486000834	Fridge	No		151	
Topline			Fridge/Freezer	Yes		161	PTC Black Danfoss Pair Compressors
Topline			Fridge/Freezer	Yes		162	PTC Black Danfoss Pair Compressors
Tricity	39879P	048004460	Fridge/Freezer			299	Twin Compressor unit see also 300
Tricity	39879P	048004460	Fridge/Freezer	Yes		300	PTC Black Danfoss Damaged twin Unit 299
Tricity Bendix	ECD028W	41100894	Fridge/Freezer	Yes	01/94	149	PTC A394
Tricity Bendix	ECD028W	44200149	Fridge/Freezer	Yes	05/94	150	PTC A4L4
Tricity Bendix	TB 110FF	94110498	Fridge/Freezer		09/99	327	PTC KLIXON
Tricity Bendix	ECD936	72700122		Yes	03/97	39	PTC Klixon

PTC							
Make	**Model**	**Ser no**	**Type**	**PTC**	**Age**	**Ref**	**Comments**
Tricity Bendix	ECD029W	42100054	Fridge/Freezer	Yes	02/94	84	PTC A 1E4
Unknown	HBP1760	D13077	Fridge Built in	Yes		309	PTC Black Danfoss Acid Damaged
Unknown			Freezer Chest	Yes		333	PTC Black Danfoss
Unknown			Fridge/Freezer	Yes		346	PTC Black Danfoss damaged
Unknown			Fridge Built in	Yes		52	PTC Black Danfoss
Unknown			Fridge	Yes		97	PTC White Danfoss Fitted Fridge
Unknown			Fridge	Yes		98	PTC Black Danfoss Fitted Fridge
Vanilla	Van-N1		Fridge	Yes	09/95	135	PTC A1N5
Vanilla	KS22.S	00800--64	Fridge/Freezer	Yes		70	PTC 2019/D1
Vestfrost	HF 201/G	42616857	Chest Freezer	Yes		266	Black Danfoss
Vestfrost	KS385G	84601307	Fridge/Freezer	Yes		310	PTC White Danfoss
Whirlpool	G2PFRU/WH	0330015673	Freezer	Yes		126	PTC White Danfoss
Whirlpool	ARG 716/G/WP	50 9511 012300	Fridge	Yes		140	PTC 2019/BC5
Whirlpool	ARG 995-K/R	500123027231	Fridge/Freezer	Yes	06/01	188	PTC AHE1
Whirlpool	A CLASS ARZ983/H	110210001706	Fridge/Freezer	Yes	02/02	190	PTC 07121/D
Whirlpool	A CLASS ARZ983/H	110210001718	Fridge/Freezer	Yes	02/02	196	PTC 07121/D
Whirlpool	A CLASS ARZ983/H	110210001717	Fridge/Freezer	Yes	02/02	203	PTC 07121/D
Whirlpool	ARG 716/WP	TR 934102669	Fridge	Yes		218	
Whirlpool	AFB904G	50 015 006472	Freezer	Yes	12/00	256	PTC Klixon type with OL
Whirlpool	ARG420/R	50 0110015200	Fridge	Yes	11/00	257	PTC AD8
Whirlpool	AFB 823/3	500322009203	Freezer Built in	Yes		261	PTC White Danfoss
Whirlpool	ART 501/G/WP	509620018532	Fridge/Freezer	Yes		270	PTC 2019/BD6
Whirlpool	AFB 433/G	850443315000	Freezer	Yes		55	PTC 2019 W94
Whirlpool			Fridge Built in	Yes		63	PTC Aspera

PTC							
Make	**Model**	**Ser no**	**Type**	**PTC**	**Age**	**Ref**	**Comments**
Whirlpool	50 9920 022965	8564 500 15020	Fridge/Frezer	Yes	04/99	8	PTC 07061/D
Zanussi	ZT52/2R	923530624	Fridge	Yes	02/01	115	PTC A6C1
Zanussi	DA1-20	32900477	Fridge	Yes		131	PTC Part Clixon Part Unidad
Zanussi	ZFC50/17	54800029	Fridge/Freezer	Yes	10/95	136	PTC A DN5
Zanussi	ZECL159W	34060170	Fridge	Yes		166	PTC White Danfoss
Zanussi	ZF 61/27	34200879	Fridge/Freezer	Yes	09/93	17	PTC A L93
Zanussi	ZL56W	14000309	Fridge	Yes	07/01	174	PTC A9L1 8100
Zanussi	ZKC 45L	923505600	Fridge Built in	Yes	09/96	180	PTC A BL6 Removed fan.
Zanussi	DF50/31	23801569	Fridge/Freezer	Yes		20	PTC Unidad
Zanussi	ZR25/1W	14000099	Fridge	Yes		208	PTC Compela with klixon
Zanussi	DR50/2	23000782	Fridge	Yes	04/92	223	PTC AF92
Zanussi	ZF56L	34600825	Fridge	Yes	10/93	227	PTC AM93
Zanussi	ZX56/4S1	24700062	Fridge/Freezer	Yes	11/02	235	PTC Aspera
Zanussi	ZF45/30 SS side by side	34800073	Fridge/Freezer	No		238	
Zanussi	ZCF56/38FF	61000530	Fridge/Freezer	Yes	12/95	265	PTC A GA6
Zanussi	ZFC 61/27	42400115	Fridge/Freezer	Yes	05/94	267	PTC A5E4 Broken PTC
Zanussi	ZFC 45/30 SS	42800181	Freezer	Yes	03/94	272	PTC A7F4
Zanussi	ZFK\61/27R	85 00204	Fridge/Freezer	Yes		3	PTC White A7NQ
Zanussi	DF 177/35-A	20100027	Fridge/Freezer	Yes		311	PTC Black Danfoss Acid Damaged
Zanussi	DF 177/35-A	20100027	Fridge/Freezer	No		312	Twin Unit other 311
Zanussi	ZKC 49/3/A	620 00073	Fridge Built in	Yes	02/96	318	PTC A206
Zanussi	ZX56/4 S1	34000108	Fridge/Freezer	Yes		329	
Zanussi	ZFC 56L	61501007		Yes	02/96	35	PTC AC6
Zanussi	Z918/8R	18 008019	Fridge/Freezer	No		36	