Toxic Species and Particulate Emissions from Synthetic Polymer Fires

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The candidate confirms that the work submitted is her own, except where work which has formed part of jointly-authored publications has been included. The contribution of the candidate and the other authors to this work has been explicitly indicated below. The candidate confirms that appropriate credit has been given within the thesis where reference has been made to the work of others.

1) **Mat Kiah M.H.**, Mustafa B.G., Andrews G.E., Phylaktou H.N., Li H (2019). **PVC Sheathed Electrical Cable Fire Smoke Toxicity**, Proceedings of the Ninth International Seminar on Fire and Explosion Hazards, St. Petersburg, Russia (April, 2019).

(Included in Chapter 4)

All the experimental work, analysis of results and writing up of the publication were carried out by Miss Hasimawaty Binti Mat Kiah. Bintu Grema Mustafa participated in carrying out the experimental procedures as two students are required when undertaking experiments and I participated in her work relating to the toxic hazards of commercial wood products. Dr Herodotos Phylaktou, Professor Gordon Andrews and Dr Hu Li (particle number specialist) supervised the research work and proof-read the publication.

On-going and other joint publications are listed in Appendix A.

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Abstract

Overall fire statistics and residential and industrial fires in which there have been large number of fatalities demonstrate that the cause of most deaths can be attributed to effects of toxic smoke produced in these fires. Despite this fact there are no national or international legal requirements to determine the toxic emissions from materials used in construction, electrical cabling or the wide range of polymer based products used in house construction and industry. Many polymers used commercially are fire retarded and the materials used for this can add to the toxicity. The only indirect control comes through some test requirements for product classification based on the volume of smoke production. However, this is not an adequate approach to the problem. Fire smoke contents can cause death directly or can impair escape so that people die indirectly from the effects of toxic gases, and in the first we need to identify and quantify these emissions for different materials and under different fire conditions. Currently, as a consequence of this lack of legal requirements, there is a dearth of data on toxic emissions from real industrial products under fire conditions.

This research was focused on toxic gas emissions under fire conditions from practical industrial polymeric materials: insulating foams, electrical cables, Polyethylene and Polystyrene goods together with some other polymeric materials: rubber, GRP, PVC pipes and clear Acrylic. All were either used by industry who gave samples for testing or were on sale in construction product retailers. Some of the goods were fire retarded and had HCl, HBr or HF in the product gases or had high ash content. These generally produced higher toxic emissions than non-fire retarded products.

Most of the work was carried out using the Leeds University modified Cone Calorimeter with raw gas sampling from a chimney above the cone outlet. A heated sample line, heated filter and heated sample pump with heated FTIR was the method of analysis used. All products were found to have significant toxic gas emissions, but the most important toxic gas depended on the material tested and was rarely CO. A data set of toxic emissions and toxic gas yields was produced which is greater than most data sources in the literature for synthetic polymer materials.

Part of this work was the modification of the Purser Furnace by adding raw hot gas sampling and eliminating the backflow of dilution air into the reaction tube. This took a long time to design and construct and was only available at the end of the research work where it was used with PE samples at lean and rich equivalence ratios.

A significant part of the work was the first use of this equipment for particle size analysis using the DMS 500 instrument. Ultra fine particles (<50nm) were present in all the fires and were a significant health hazard.

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Nomenclature and Symbols

CO	Carbon monoxide
CO_2	Carbon dioxide
HCN	Hydrogen cyanide
HBr	Hydrogen bromide
HCl	Hydrogen chloride
HF	Hydrogen fluoride
N_2	Nitrogen
O_2	Oxygen
SO_2	Sulphur dioxide
Φ	Equivalence ratio
%	Percent
^{o}C	Unit temperature – degree Celsius
kW	Unit energy – kilowatt
m^2	Unit area – meters square
g/g	Yield unit – gram/gram
ppm	Part per million
s	Unit time – seconds
dm^3	Unit volume – cubic decimetre
m3	Unit volume – cubic metre
min	Unit time – minutes
mm	Unit length – millimetre
nm	Unit length – nanometre
g	Unit mass – gram
L	Unit volume – litre
vol.	Volume
wt.	Weight
ŋ	Combustion efficiency

Chapter 1
Introduction

Fire toxicity is one of the main causes of death and injury in fires in buildings. Statistics in the UK [1] show that toxic smoke inhalation accounts for about 60% of the total deaths in fires. However, currently there are no regulations that require the toxic emissions from the burning of building to be determined and taken into account. This project tests the fire toxicity of various polymeric materials used in the construction and contents of buildings. Other than gas toxicity, small particle size also a significant fire hazard. This hazard had been studied and measured from a small range of size (5nm).

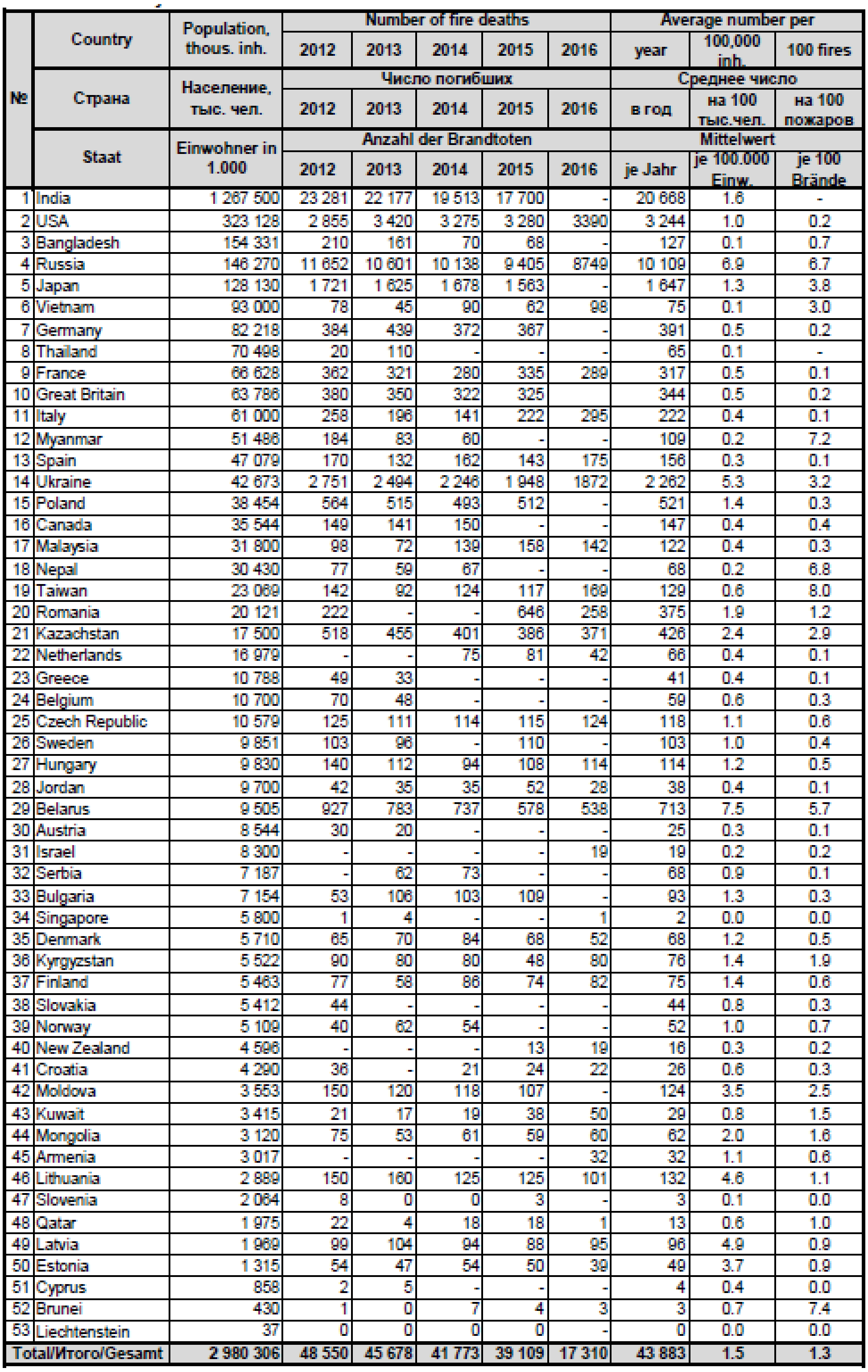
1.1 Fire Statistics

As reported by the recent World Fire Statistics 2018 [2] and reproduced in Table 1.1, in consideration of 53 countries, India gave the highest number in fire deaths from year 2012 to 2016 with the fire death average number per year of 20,668. Russia gave the highest number of fire deaths for year 2016 which was about 50 percent (8,749 deaths) of the total world fire deaths (17,310 deaths), followed by USA with 3,390 deaths and Ukraine with 1,872 deaths. Meanwhile the total fire deaths in Great Britain in 2016 was 367 deaths and in Malaysia was 142 deaths with average number per year 344 and 122 deaths. Figure 1.1 (a) shows the total number of world fires categorised by type of environment in which the fires took place – the biggest fraction, 35.5 percent involved structure fires, 22.1 percent involved grass and forest fires, 13.5 percent involved vehicle fires, highlighting the importance of structural fires. Structural fires are the most hazardous to human life as it is where the highest concentration of people.

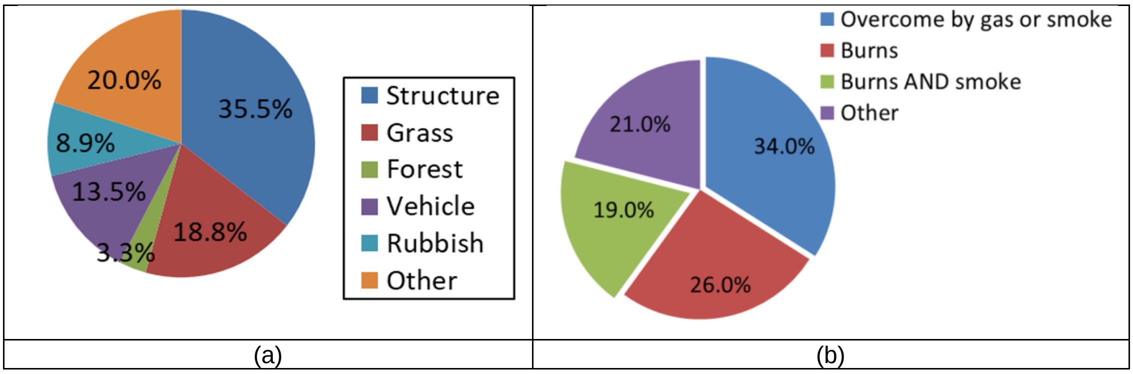
In the last few decades, the development in the fire safety research has led to the growth of fire toxicological studies. Before that, the well-known fire hazards were limited to thermal hazards only [3]. Fire statistics now show that the main cause of fire deaths is by smoke inhalation, not by heat burns.

In Great Britain the cause of death in fires has been attributed mainly the effects of smoke typically 40% due to “smoke” and another 20% due to the combination of “smoke and heat” with only 20% attributed to “heat” alone (the balance being “unspecified” or “other”). The 2013/14 statistics [8] are typical of these with three main categories being 41, 20 and 20 % respectively. The most recent (2018/19) breakdown [9], is shown in Fig. 1.1 (b).

Table 1.1 Trends in fire deaths in the countries of the World in 2012-2016 [2].



№	Country	Population, thous. inh.	Number of fire deaths					Average number per		
			2012	2013	2014	2015	2016	year	100,000 inh.	100 fires
	Страна	Население, тыс. чел.	Число погибших					Среднее число		
			2012	2013	2014	2015	2016	в год	на 100 тыс.чел.	на 100 пожаров
	Staat	Einwohner in 1.000	Anzahl der Brandtoten					Mittelwert		
			2012	2013	2014	2015	2016	je Jahr	je 100.000 Einw.	je 100 Brände
1	India	1 267 500	23 281	22 177	19 513	17 700	-	20 668	1.6	-
2	USA	323 128	2 855	3 420	3 275	3 280	3390	3 244	1.0	0.2
3	Bangladesh	154 331	210	161	70	68	-	127	0.1	0.7
4	Russia	146 270	11 652	10 601	10 138	9 405	8749	10 109	6.9	6.7
5	Japan	128 130	1 721	1 625	1 678	1 563	-	1 647	1.3	3.8
6	Vietnam	93 000	78	45	90	62	98	75	0.1	3.0
7	Germany	82 218	384	439	372	367	-	391	0.5	0.2
8	Thailand	70 498	20	110	-	-	-	65	0.1	-
9	France	66 628	362	321	280	335	289	317	0.5	0.1
10	Great Britain	63 786	380	350	322	325		344	0.5	0.2
11	Italy	61 000	258	196	141	222	295	222	0.4	0.1
12	Myanmar	51 486	184	83	60	-	-	109	0.2	7.2
13	Spain	47 079	170	132	162	143	175	156	0.3	0.1
14	Ukraine	42 673	2 751	2 494	2 246	1 948	1872	2 262	5.3	3.2
15	Poland	38 454	564	515	493	512	-	521	1.4	0.3
16	Canada	35 544	149	141	150	-	-	147	0.4	0.4
17	Malaysia	31 800	98	72	139	158	142	122	0.4	0.3
18	Nepal	30 430	77	59	67	-	-	68	0.2	6.8
19	Taiwan	23 069	142	92	124	117	169	129	0.6	8.0
20	Romania	20 121	222	-	-	646	258	375	1.9	1.2
21	Kazachstan	17 500	518	455	401	386	371	426	2.4	2.9
22	Netherlands	16 979	-	-	75	81	42	66	0.4	0.1
23	Greece	10 788	49	33	-	-	-	41	0.4	0.1
24	Belgium	10 700	70	48	-	-	-	59	0.6	0.3
25	Czech Republic	10 579	125	111	114	115	124	118	1.1	0.6
26	Sweden	9 851	103	96	-	110	-	103	1.0	0.4
27	Hungary	9 830	140	112	94	108	114	114	1.2	0.5
28	Jordan	9 700	42	35	35	52	28	38	0.4	0.1
29	Belarus	9 505	927	783	737	578	538	713	7.5	5.7
30	Austria	8 544	30	20	-	-	-	25	0.3	0.1
31	Israel	8 300	-	-	-	-	19	19	0.2	0.2
32	Serbia	7 187	-	62	73	-	-	68	0.9	0.1
33	Bulgaria	7 154	53	106	103	109	-	93	1.3	0.3
34	Singapore	5 800	1	4	-	-	1	2	0.0	0.0
35	Denmark	5 710	65	70	84	68	52	68	1.2	0.5
36	Kyrgyzstan	5 522	90	80	80	48	80	76	1.4	1.9
37	Finland	5 463	77	58	86	74	82	75	1.4	0.6
38	Slovakia	5 412	44	-	-	-	-	44	0.8	0.3
39	Norway	5 109	40	62	54	-	-	52	1.0	0.7
40	New Zealand	4 596	-	-	-	13	19	16	0.3	0.2
41	Croatia	4 290	36	-	21	24	22	26	0.6	0.3
42	Moldova	3 553	150	120	118	107	-	124	3.5	2.5
43	Kuwait	3 415	21	17	19	38	50	29	0.8	1.5
44	Mongolia	3 120	75	53	61	59	60	62	2.0	1.6
45	Armenia	3 017	-	-	-	-	32	32	1.1	0.6
46	Lithuania	2 889	150	160	125	125	101	132	4.6	1.1
47	Slovenia	2 064	8	0	0	3	-	3	0.1	0.0
48	Qatar	1 975	22	4	18	18	1	13	0.6	1.0
49	Latvia	1 969	99	104	94	88	95	96	4.9	0.9
50	Estonia	1 315	54	47	54	50	39	49	3.7	0.9
51	Cyprus	858	2	5	-	-	-	4	0.4	0.0
52	Brunei	430	1	0	7	4	3	3	0.7	7.4
53	Liechtenstein	37	0	0	0	0	-	0	0.0	0.0
Total/Итого/Gesamt		**2 980 306**	**48 550**	**45 678**	**41 773**	**39 109**	**17 310**	**43 883**	**1.5**	**1.3**



(a) (b)

Figure 1.1 Fire distribution by (a) types in worldwide (2016) [2] and (b) causes of fire deaths in Great Britain for 2018/19 [4].

The causes of fire-related deaths are fairly stable across recent years, except for 2017/18 where the ‘other’ category was higher (27% compared with a usual range of between 10–20%) due to the Grenfell Tower fire - a large proportion of the fatalities are recorded as ‘unspecified’ while the public inquiry is still ongoing [9].

Smoke produced in fires normally contains toxic gases, vapour and various sizes of particulates. While the fire deaths are mainly attributed to the effects of smoke in terms of visibility and toxicity and most of previous fire toxicity studies are found to be focused more on the determination of toxic potency of fire effluents based on gas-phase products compared to particle-phase products. the effect of particulates has only recently started receiving attention. There are currently only a limited number of studies [5-7] which focus on the determination of particulate size from fires. As awareness on the health and environmental impact from particles generated in fires has increased, it is vital to conduct research in order to investigate the particulates emissions from the combustion of different materials and their effects on human health other than to be only focused on the toxic gases emission from the fire. This work will present data on both gaseous and particulate yields.

The latest Fire Rescue and Incident Statistics in England for year ending September 2019 [1] as in Figure 1.2, it showed a decrease of 31 percent of fire deaths which gave 248 fire deaths compared with year 2017 which gave 362 fire deaths including 72 from the Grenfell Tower fire. From the data, most of fire deaths involve fires in dwellings and other buildings compared to other locations such as road vehicles and other outdoor. This statistic has raised a critical concern to researchers when knowing that between these fire locations, even number of fires occurred are much lower for building fires than for chimney, road vehicle and other outdoor fires but it has contributed to a high number of the total fire deaths. This consideration has become one of the reasons why the present work focussing on investigating the toxic gases and particulate emissions from building material fires. Table 1.2 shows a statistic of fire incident number by type comparing the year ending September 2019 with the year ending September 2018, five years previously in 2013/14 and ten years previously (where available) in 2008/09 in Great Britain. Fire related fatalities in dwellings had shown an increase of 9% in 2019 compared to 2018.

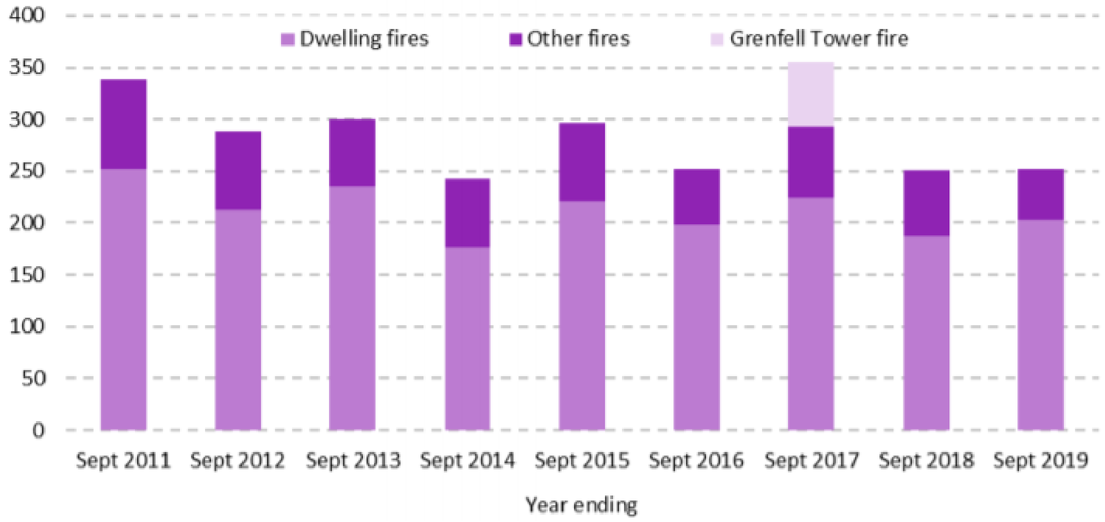
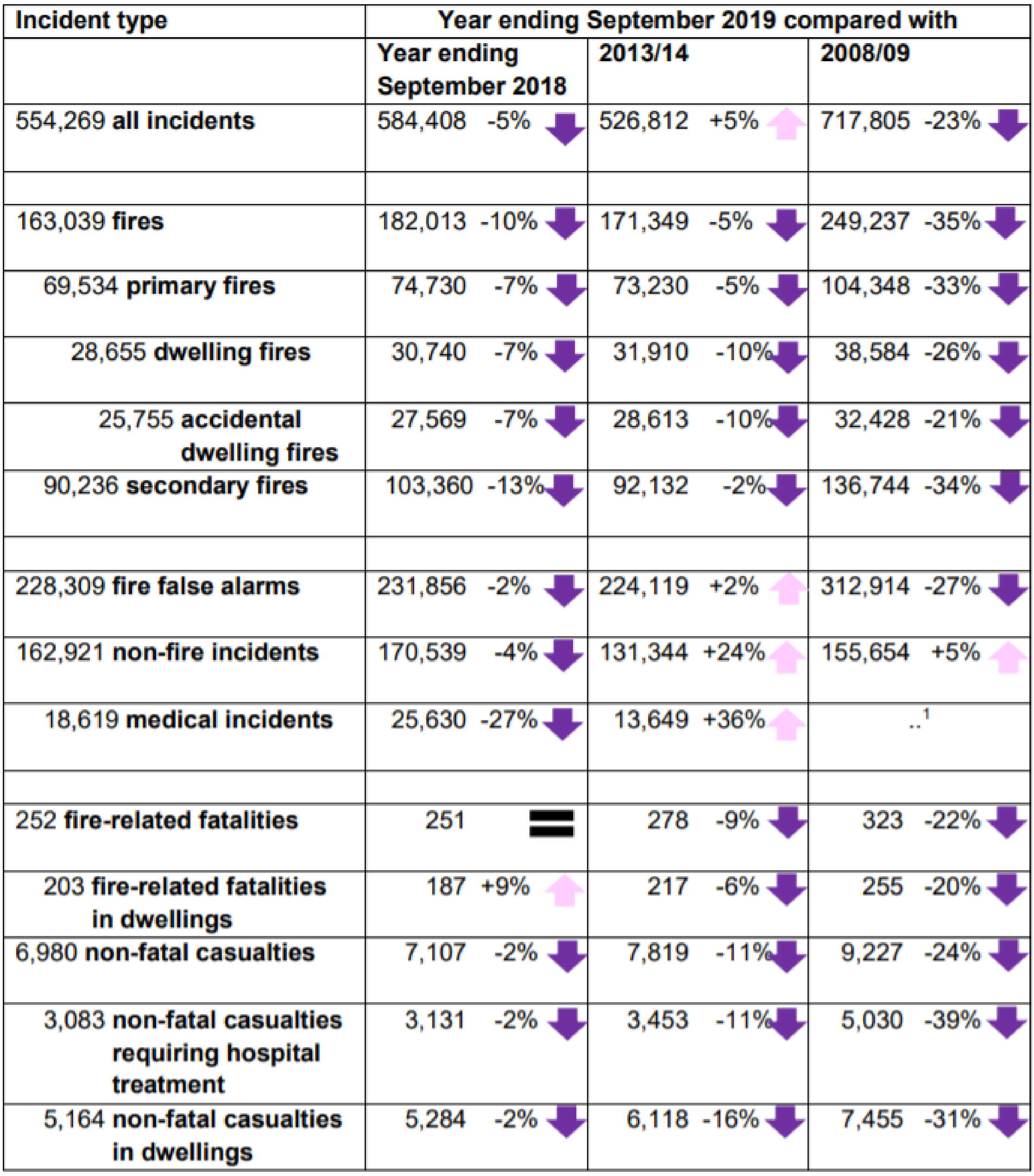


Figure 1.2 Total fire-related fatalities, England; year ending September 2011 to year ending September 2019 [1]

Table 1.2 Fire incident types in Great Britain from 2008 to September 2019 [1].



Incident type	**Year ending September 2019 compared with**		
	Year ending September 2018	**2013/14**	**2008/09**
554,269 **all incidents**	584,408 -5% ↓	526,812 +5% ↑	717,805 -23% ↓
163,039 **fires**	182,013 -10% ↓	171,349 -5% ↓	249,237 -35% ↓
69,534 **primary fires**	74,730 -7% ↓	73,230 -5% ↓	104,348 -33% ↓
28,655 **dwelling fires**	30,740 -7% ↓	31,910 -10% ↓	38,584 -26% ↓
25,755 **accidental dwelling fires**	27,569 -7% ↓	28,613 -10% ↓	32,428 -21% ↓
90,236 **secondary fires**	103,360 -13% ↓	92,132 -2% ↓	136,744 -34% ↓
228,309 **fire false alarms**	231,856 -2% ↓	224,119 +2% ↑	312,914 -27% ↓
162,921 **non-fire incidents**	170,539 -4% ↓	131,344 +24% ↑	155,654 +5% ↑
18,619 **medical incidents**	25,630 -27% ↓	13,649 +36% ↑	..[1]
252 **fire-related fatalities**	251 =	278 -9% ↓	323 -22% ↓
203 **fire-related fatalities in dwellings**	187 +9% ↑	217 -6% ↓	255 -20% ↓
6,980 **non-fatal casualties**	7,107 -2% ↓	7,819 -11% ↓	9,227 -24% ↓
3,083 **non-fatal casualties requiring hospital treatment**	3,131 -2% ↓	3,453 -11% ↓	5,030 -39% ↓
5,164 **non-fatal casualties in dwellings**	5,284 -2% ↓	6,118 -16% ↓	7,455 -31% ↓

1.2 Notable Relevant Fires

Below is a brief summary of some well known fires in which the toxicity of the fire products was the main contributor to the mass fatalities of these fires. A list of other fires relevant to this project, involving cladding materials is also given in Table 1.3.

1.2.1 Grenfell Tower

Grenfell Tower fire happened on June 14, 2017 and took away 72 lives including one victim who died in the hospital seven months after the incident and around 70 injured [8]. As generally reported, the fire on this 24-storey residential tower block was started by a malfunctioning fridge-freezer on the fourth floor which then spread rapidly up the building's exterior, bringing fire and smoke to all the residential floors. This fire incident is one example of cladding materials based fire cases. Zinc cladding was initially considered as cladding materials for the building construction of the Grenfell Tower in 2015 but due to cost saving purpose, cladding materials like Reynobond PE and aluminium with plastic filling were finally used. There are many buildings constructed with using flammable cladding materials and many more will be in future if no further objection by rules as safety guidance. In Dubai UAE, more 70% skyscrapers were constructed with flammable cladding materials which was mainly PE. In example, Burj Kalifa Hotel fire started with an explosion and this building were constructed with 100% PE as panel cores of the cladding part. There were many fire cases around the world that involved cladding materials and some examples were listed in Table 1.3.

Whilst currently the cause of death of the 72 people in the building is currently “unspecified” (as discussed above) one of the objectives of the Public Inquiry is the determination of the cause of death. The phase 1 report from the fire Toxicology expert witness Prof. Purser [9] reported that blood toxicology from a limited number of victims (15) showed high concentrations of carboxyl haemoglobin consistent with CO poisoning. He also states that these measurements and and 999 call transcripts indicate that people who died in their flats were overcome by asphyxiant gases (CO and HCN) and died before their bodies were burned. He also identified the building cladding, PVC windows and contents of the apartments as contributors to the fatal toxic emissions.

1.2.2 The Rose Park Nursing Home

In 2004, a fire at a residential care home, the Rosepark Care Home, located in Lanarkshire, Scotland resulted in 14 deaths of elderly residents and another four residents injured [10, 11]. Fire safety procedures at this care home were found to be inadequate and deficient. As reported, the staff waited nine minutes before they contacted the fire service [11]. From the accident investigation and reconstruction tests with detailed toxic species concentration measurements [12] concluded that the elderly population of 18 residents were exposed to the same mix of fire effluents but at different levels of severity depending upon their location. Ten persons in open rooms were exposed to high concentrations, resulting in death at the fire scene within ~8–9 min of the start of the fire. Persons in more protected locations were found alive after much longer exposure times although they some of these subsequently died due to their exposure.

1.2.3 Piper Alpha

A very high number of deaths (at least 165 died) caused by the Piper Alpha initial explosion and subsequent fires at North Sea oil platform, near Aberdeen in July 1988 [13]. This incident involved pool and liquid and gas jet fires in multi-level buildings. The cause of the incident was a leak of condensate due to failures of the permit to work system which resulted in a small explosion and subsequent hydrocarbon fires which eventually destroyed the whole platform [14]. Of the diseased, a large number (109) died from smoke inhalation most of them while sheltering in the designated accommodation modules.

1.2.4 Kings Cross Fire 1988

31 died in this fire accident at the Kings Cross Railway Station which was started by smokers’ matches falling through the gap at the edge of the escalator [15]. The dirt and grease accumulated over months was the fuel ignited by the falling match below the escalator. A flashover through the ticket hall resulting from the pyrolysis of multilayers of paint is thought to have contributed to the dense toxic smoke that was associated with the fire the public inquiry that followed concluded that the toxic smoke contributed to the deaths and recommended the removal of materials known to produce toxic fumes.

Table 1.3 List of fire incidents involved cladding materials.

No.	Incident	Location	Date of Event	Number of Deaths	Number of Injuries	Cause of Fires	Information
1	EPF Building	Jalan Gasing, PJ, Selangor Malaysia, 6 storey building	13.02.2018 (14:15)	-	-	On the 1st floor due to renovation works at the back of the building	PE cladding
2	Grenfell Tower	North Kensington, London England, 24 storey flat	14.06.2017 (00:54)	72 (2 died in the hospital)	>70	Fridge-freezer faulty on 4th floor	Cladding materials used in the building were PE filler, PIR foam insulation, PU seal for joints and PVC windows
3	The Marina Torch Tower	Dubai UAE, 79 storey building	04.08.2017 (01:00)	-	-	Not known (Suspected caused by a thrown cigarette butt and it landed on a plant at a balcony)	During restorative works
4	The Marina Torch Tower	Dubai UAE, 79 storey building	21.02.2015 (02:00)	-	7 (due to smoke inhalation)	Fire started on the 50th floor	
5	Burj Khalifa Hotel	Dubai UAE, 63 storey building	31.12.2015 (New Year's Eve)			An explosion in the 39th floor	Fire started with an explosion. Flammable cladding materials (100% PE as panel cores)
6	Tamweel Residential Tower	Jumeirah Dubai UAE, 34 storey building	18.11.2012	-	-	A cigarette butt thrown into a bin	
7	Sharjah Residential Tower (Tiger 3 Building in Al Taawun)	Sharjah Dubai UAE, 40 storey building	04.03.2018 (07:03)	-	7	Flames allegedly started from a kitchen in an apartment on the 8th floor of the building.	
8	Al Buteenah Apartment	Al Buteenah, Sharjah Dubai UAE	12.02.2018 (01:12)	5 (due to suffocation)		From investigation, fire might have started from the air-conditioning unit on the 1st floor.	
9	Al Manama Supermarket	Sharjah Dubai UAE	14.04.2017	2 (died of suffocation)	5		
10	Nasser Tower	King Faisal Street, Sharjah Dubai UAE, 32 storey building	01.10.2015	-	-		
11	Hafeet Tower 2 (10 Apartments)	Al Tawun, Sharjah Dubai UAE	22.04.2013			Fire broke out on the 20th floor.	
12	10 Apartments	Al Qasimiya, Sharjah Dubai UAE, 10 storey building	12.03.2013	-	-	A blaze gut 10 apartments on the 1st floor.	

13	Al Tayer Tower	Al Nahda Park, Sharjah Dubai UAE, 40 storey building	28.04.2012				
14	Al Baker Tower 4	Al Tawun Mall, Sharjah Dubai UAE	25.01.2012			The fire was caused by a lit cigarette that was thrown off the balcony from an upper floor and landed on the balcony on the 1st floor.	
15	A High-rise Residential Tower	Al Nahda, Sharjah Dubai UAE	08.11.2011		6		
16	Al Wahda Street Apartment	Sharjah Dubai UAE	08.03.2011			Fire caused by an electric short circuit.	
17	Bu Tinah Fire	Bu Tinah, Sharjah Dubai UAE, 14 storey building	06.07.2010				
18	Al Buhaira Corniche Apartment	Sharjah Dubai UAE	04.01.2009	-		Fire started from a kitchen and gutted the apartment on the 13th floor.	
19	Abdullah Khouri Building	Jamal Abdul Nasser Street, Sharjah Dubai UAE	28.10.2008	2		Fire on the 4th floor.	
20	Al Ta'awun Residential Building	Sharjah Dubai UAE	26.05.2008	-		The fire started on the 1st storey and extended to apartments up to the 7th floor.	
21	Al Tahira Tower	Al Nahda, Sharjah Dubai UAE	21.07.2007	1	3	Fire breaks out in an apartment at the 8th floor.	
22	Majaz 2 Residential Tower	Sharjah Dubai UAE	09.04.2007			Fire tore through four floors.	
23	Al Yasmeen Apartment	Sharjah Dubai UAE	25.01.2007				
24	Dana Tower	Buhairah Corniche, Sharjah Dubai UAE, 47 storey building	09.01.2007				
25	Baku Residence Building	Baku Azerbaijan, 16-level residence building	19.05.2015	15 (toxic smoke inhalation)	63		Flammable Styrofoam facing had been installed on exterior of buildings. Flammable materials used in facade renovation.
26	Sanghai Fire	Shanghai China, 28 storey high-rise building	15.11.2010 (14:15)	58	>70	Fire started with construction materials and spread throughout the building.	
27	The Beijing Television Cultural Center Fire	Beijing China	09.02.2009 (20:27)	1 (a fire-fighter)	7	A nearby unauthorised fireworks (Chinese New Year Celebration) display caused the fire.	The building was built far less steel than conventional skyscrapers.

1.3 Particulates

Beyond the gaseous toxic emissions fires also emit large amounts of respirable particulates of various sizes which may harm the occupants and fire-fighters in different ways giving either a short term effect or a long term effect. Compared to ultra-fine particles, large particles usually will give a short term or immediate effect to the people who are exposed to them during the fire by causing irritancy to their eyes and skins which will reduce their capability to escape. As a long term effect, generation of nanoparticles (especially particle size below than 50 nm) from the combustion process may cause cancer disease to the people who has exposed to them when being absorbed through the blood line [16, 17].

The main aspects of particle toxicity relate to where they deposit in the respiratory tract, which depends on particle size, and their toxicity, which depends partly on their chemical composition and partly on their physical characteristics. In general large inhalable particles ~100-15 microns diameter, deposit in the upper respiratory tract and airways, If the carry toxic chemicals they cause acute airway inflammation, or following long term exposure (eg smoke from air pollution or tobbaco) chronic obstructive lung disease and lung cancer. Smaller particles ~0.5-5 microns diameter penetrate into the alveolar region of the lung and can cause acute lung inflammation and oedema a few hours after exposure during a fire, which can be fatal. Ultrafine and nano-particles may cause acute lung inflammation or emphysema but also cross into the blood stream where they can cause several effects depending on their chemistry and physical characteristics. These effects include polymer fume fever, cardiovascular disease (including heart attacks), and carcinogenicity.

Smaller particles can penetrate into the blood system easier than larger particles. These nanoparticles may act as transporters of absorbed and adsorbed toxic compounds (VOC or aerosols) into the lungs the blood stream and vital organs. Polycyclic aromatic hydrocarbons (PAH) such as Benzene and Naphthalene are the example of toxic compounds that may cause the cancer decease to the humans when they breathe in these particles during the fire. In 2014, there was a fire death case which was due to cancer decease where three fire fighters died on the same day after 13 years giving service as responders in the fire incident of the World Trade Centre, USA because of their direct exposure to the toxic species and particulates [17]. It is very important to do further investigations on the particle size and particle distribution from fires in order to be able to control and prevent this kind of hazard from harming the people who are directly exposed.

Measurement of particulate yields and characterisation of particle size distribution is an important objective of this project.

1.4 Legislation

Most of fire deaths are generally involved in building fires. Building fire cases have involved various kinds of building structures such domestic or private home fires, high rise living accommodation fires, commercial and industrial building fires, public place building fires and also care centre fires.

There are various types of combustible materials used in building construction. Wood is the most common building material which is widely used compared to other materials like polymers. Due to an increase in demand for synthetic materials, cost savings with an advanced industrial production process, these synthetic materials have become a favourable option by the contractors and the end users. Even furniture, tools and small appliances are widely made by the synthetic materials.

Combustible building construction materials mostly used is wood, only 20 percent usage involved other materials which are mainly polymers. Polymer fires may produce gases which are more toxic than the wood fires depending to the type of polymer burnt, in example Polyisocyanurate (PIR) based materials will produce Hydrogen cyanide (HCN) which is toxic even at low concentration level. PVC based materials will produce irritant gases that can cause irritancy effects when burned which may impair the people who exposed to it from escape during the fire event. As for today, there is no regulation yet found to stop of using PVC or other harmful polymers in buildings.

The British standards for toxicity provide a guidance for the escape/safety of occupants where there is stated that there must be enough time to reach a place of safety without any harm [18-20]. From the existing standards, regarding the toxicity, only smoke obscuration is mentioned and the illustration of smoke alarms [18]. Smoke spread from the origin, hot gas layer and smoke optical density are the main parameters related to the application of fire safety engineering [19]. Although there are tenability limits defined in terms of exposure to toxic and irritants fire gases there is legal requirement to control the use of such materials based on their toxic yields in fire. The only control that may translate to an indirect control of toxicity is the visibility requirement for safe escape and by controls of reaction-to-fire properties of products [20].

1.5 General Research Aims

In overall, the present work mainly aims to highlight and investigate the toxicity dangers of various electrical cables and polymers sold commercially for buildings using two different test methods, an existing modified Cone Calorimeter and a new developed Purser Furnace System with attachment to several external analysers such as Fourier Transform Infrared Spectroscopy (FTIR), Oxygen Analyser, Particle Sizer (DMS500) and Smoke Meter. The FTIR and Oxygen analyser were used to measure the toxic gases. For measurement of the particulate sizes, a particle size equipment called the Cambustion DMS500 was used. Smoke meter was also used to measure soot mass collected on the placed filter papers. Series of fire tests were conducted under different realistic fire conditions from well to under-ventilated fires. More than 40 polymers were burned and tested including the electrical cables. General research objectives are as follow:

a) Develop a methodology for the analysis of toxic gases and particulates in the Cone Calorimeter and the steady state tube furnace.

b) Design, construct and commissioning the new developed Purser Furnace System.

c) Provide data of combustion and fire toxicity properties such as heat release rate, equivalence ratio, mass loss rate, toxic gas concentration, total toxicity, major gas contribution, gas and particulate yields and particle size and number distributions from polymer fires.

d) Compare the results from both Cone Calorimeter and Purser Furnace methods.

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A.2 List of Conferences and Presentations

1) ISFEH9 2019 – St. Petersburg, Russia, April 21-26, 2019, PVC Sheathed Electrical Cable Fire Smoke Toxicity, (Oral).
2) ISFEH9 2019 – St. Petersburg, Russia, April 21-26, 2019, Toxic Gases from PU and PIR Foam Fires (Poster).
3) Fired-UP 2018 – University of Edinburgh, United Kingdom, May 17-18, 2018, Toxicity of electrical cable fires under restricted and free ventilations in the Cone Calorimeter (Oral).
4) Cambridge Particle Meeting 2017 – University of Cambridge, United Kingdom, June 23, 2017.
    a) Particle size distribution as a function of time during pine wood combustion on a cone calorimeter (Oral, presented by Dr Hu Li).
    b) Particle size emissions from PVC electrical cable fires (Poster).
5) MySECON2017 2017 – University of Manchester, United Kingdom, May 12, 2017. Toxic species and particle size distribution from PVC cable fires (Poster).