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The Performance of Mains-Powered Residential Smoke Alarms with a Backup Energy Source

Abstract

Mains-powered residential smoke alarms are considered more reliable than equivalent battery-powered devices since it is not necessary to have an annual battery replacement and there less chance that the home occupier will remove the battery for some reason. However, the reliability of residential smoke detection systems comprising of mains-powered devices can be further improved by the use of a backup energy source. This allows a smoke alarm to continue operating if the mains supply becomes unavailable.

This paper examines the long-term performance of a range of energy sources that are used as backup for mains-powered smoke alarms. The paper reports on the results from a research programme that has be running for over four years in which energy sources have been tested in both standby and alarm modes.

1 Introduction

1.1 Background

The benefit of using smoke alarms is recognised in the 1992 revisions to the UK's Approved Document B of the Building Regulations [1] which recommends that all newly constructed dwellings should have a linked mains-powered domestic smoke alarm on each floor. As noted in BS 5839 Part 6 [2], the reliability of systems comprising of mains-powered smoke alarms can be improved by the use of a backup energy source. This allows a smoke alarm to continue operating when the mains supply is unavailable.

The majority of homes in the UK now have at least one domestic smoke alarm installed [3, 4]. These devices are only of benefit to the occupants in a fire when they are operating correctly. A US study of domestic smoke alarms [5] found that around one fifth were not operational, mainly because of non-functioning power sources. Nearly all of these non-operating devices had missing, flat or disconnected batteries. The use of smoke alarms powered by the mains electricity supply eliminates the problems of battery removal and flat batteries.

In the UK, the mains AC electricity supply can be considered a reliable source. However, there are cases where the supply may become accidentally or deliberately disconnected. The frequency and duration of any disconnections will depend on several factors such as the location of the property and the type of tenant. The use of a backup energy source would allow a smoke alarm to continue operating until the mains supply is re-established. A backup power supply will also maintain the operation of a smoke alarm should the mains power be lost during a fire (early on, before the alarm is heard) or as a result of the fire being due to an electrical fault that interrupts the supply.

Should a mains-powered smoke alarm with a backup energy source become disconnected from the AC power it will continue to function using the backup energy source. The capacity of the energy source determines how long the smoke alarm can operate and raise an alarm in case of fire. If the backup supply voltage drops below a particular threshold, an audible warning is given. If the voltage continues to drop, it will reach a certain point where the sounder will no longer be able to function but the low power warning will continue to operate. A further drop in the voltage will result in failure of the low power warning. The particular voltage levels at which these events occur vary between devices but typical values are 7.5 V for the low power warning to commence, 4.5 V for the sounder to fail and 3.5 V for the low power warning to fail.

A range of mains-powered smoke alarms is available in which various types of backup energy source are used. Each type of backup source has particular advantages and disadvantages. Backup supplies can be considered to consist of two broad categories; primary and rechargeable as described below. This paper considers the different types available and compares their performance. It is not the intention, nor is it possible, to declare that any one type of backup source is 'better' than any other as the selection of backup energy sources depends on many factors:

1. Cost - the type of backup source has an influence on the initial purchase cost of the smoke alarm and also subsequent maintenance where the backup supply may need servicing or replacing,
2. Shelf life - the life of the source while not in use and any storage requirements,
3. Operating power capacity - the available power when no mains power is being supplied,
4. Alarm power capacity - the available capacity during an alarm,
5. Recharge time - the length of time for the backup supply to recharge after full or partial usage where appropriate,
6. Safety - any risks to the user or maintenance personnel during normal operation or if the backup energy source is misused,
7. Environmental considerations - the cost and requirements for the eventual disposal of the smoke alarm that includes its accompanying backup power source.

1.2 Primary cells

Cells with irreversible reactions are commonly known as primary cells and are available in a number of forms: zinc carbon, zinc chloride, alkaline manganese and lithium. The standard 9V PP3 primary cells, in particular zinc carbon and alkaline have been used in smoke alarms for many years and have been shown to operate effectively, powering smoke alarms for extended lengths of time. However the user can remove primary cells and although several manufacturers have designed their mains-powered smoke alarms to limit removal of this form of backup energy source, it is not possible to eliminate such abuse.

Zinc carbon cells (or ‘Leclanché’ cells) were the first primary batteries made available for household use. The zinc chloride battery is a development of the zinc carbon battery and it is used where the higher energy of alkaline is not required. Currently alkaline manganese is the most commonly used primary cell and although it is suited to high current drain applications, the very low self-discharge current also allows for low drain uses such as smoke alarms. Lithium cells are available in a range of chemistries that are suited to different current drain applications. The cells have a very long shelf life due to extremely low self-discharge rates. Standard size PP3 lithium manganese dioxide batteries are available which can be fitted to smoke alarms that accept primary cells. It is reported that these cells should be able to power a smoke alarm for between five [6] and ten years [7].

1.3 Rechargeable cells

There are several types of rechargeable technology available as a backup power sources for smoke alarms; Nickel cadmium (NiCd), super-capacitor and rechargeable lithium.

NiCd batteries are used extensively in a range of applications such as rechargeable power tools and portable electronic equipment. The type of NiCd cell used in many smoke alarms cannot be removed by the user although PP3 size NiCd cells are available that could be used as a rechargeable substitute for primary cells. The recharge time of NiCd cells is relatively long compared with other technologies and they can exhibit a ‘memory effect’ where continual partial discharging and recharging can reduce their capacity. Cadmium is a ‘heavy’ metal and should not be allowed to contaminate the environment and the disposal of devices containing NiCd batteries may require special procedures particularly where large numbers are involved.

The super-capacitor (or memory capacitor) technology was introduced into the smoke alarm market in around 1991. The performance of the super-capacitor may be influenced by temperature although in normal domestic environments this should not be a problem. Compared with other rechargeable technologies the recharge time of the super-capacitor is relatively quick however their power capacity is less. The cells are environmentally friendly, as they do not contain any toxic material.

Rechargeable lithium cells are the latest technology to be used as a backup power source and they reportedly do not exhibit the memory effect. They also do not contain heavy metals, however, lithium should not be put in a persons mouth or swallowed. Lithium is potentially explosive which can cause particular problems for recycling and in landfill sites.

1.4 Testing arrangements

This study was carried out in collaboration with the Building Research Housing Group (BRHG), a group of local authorities and housing associations with interests in public housing needs. The BRHG members supplied a representative selection of mains-powered domestic smoke alarms to FRS for the study. These devices were tested both when connected to the mains AC supply and in standby mode with the backup supply voltage measured either daily or weekly depending on the type of source and the testing procedures. In addition, some stand-alone smoke alarms (i.e. devices that use primary cells as their only source of power) were also tested as part of the study.

2 Backup supply performance

2.1 Primary cells

Figure 1 shows typical voltage discharge profiles for three types of primary cell installed in mains-powered smoke alarms operating in standby mode. After about 8 months the device containing zinc chloride cell began to give the low power warning. However, the battery continued to supply a sufficiently high enough voltage to power the device for at least another 1000 days while continuing to give a low power warning.

The early battery warning and the extent of the standby capacity of the zinc chloride cell were somewhat unexpected. It appears that this particular device had its low power warning threshold set too high.

Three test modes are shown for the alkaline cells; (1) optical sensor smoke alarm without weekly test, (2) ionisation sensor with a sounder tested for five seconds once per week, (3) stand-alone dual optical/ionisation sensor smoke alarm without weekly test. The smoke alarm containing the optical sensor gave a low power warning after 855 days however the other two devices have yet to reach their low power warning thresholds.

The results for the lithium primary cell exhibits an almost flat profile with no appreciable reduction in the voltage demonstrating that it can continue to fully power a smoke alarm for at least four years.

2.2 Rechargeable NiCd

Figure 2 shows the performance of a NiCd backup energy source in an ionisation smoke alarm over a series of discharge cycles. The first discharge cycle gave a standby time of around 75 days. After the third discharge the cell shows a degraded performance with the low power warning given at an earlier time than previously.

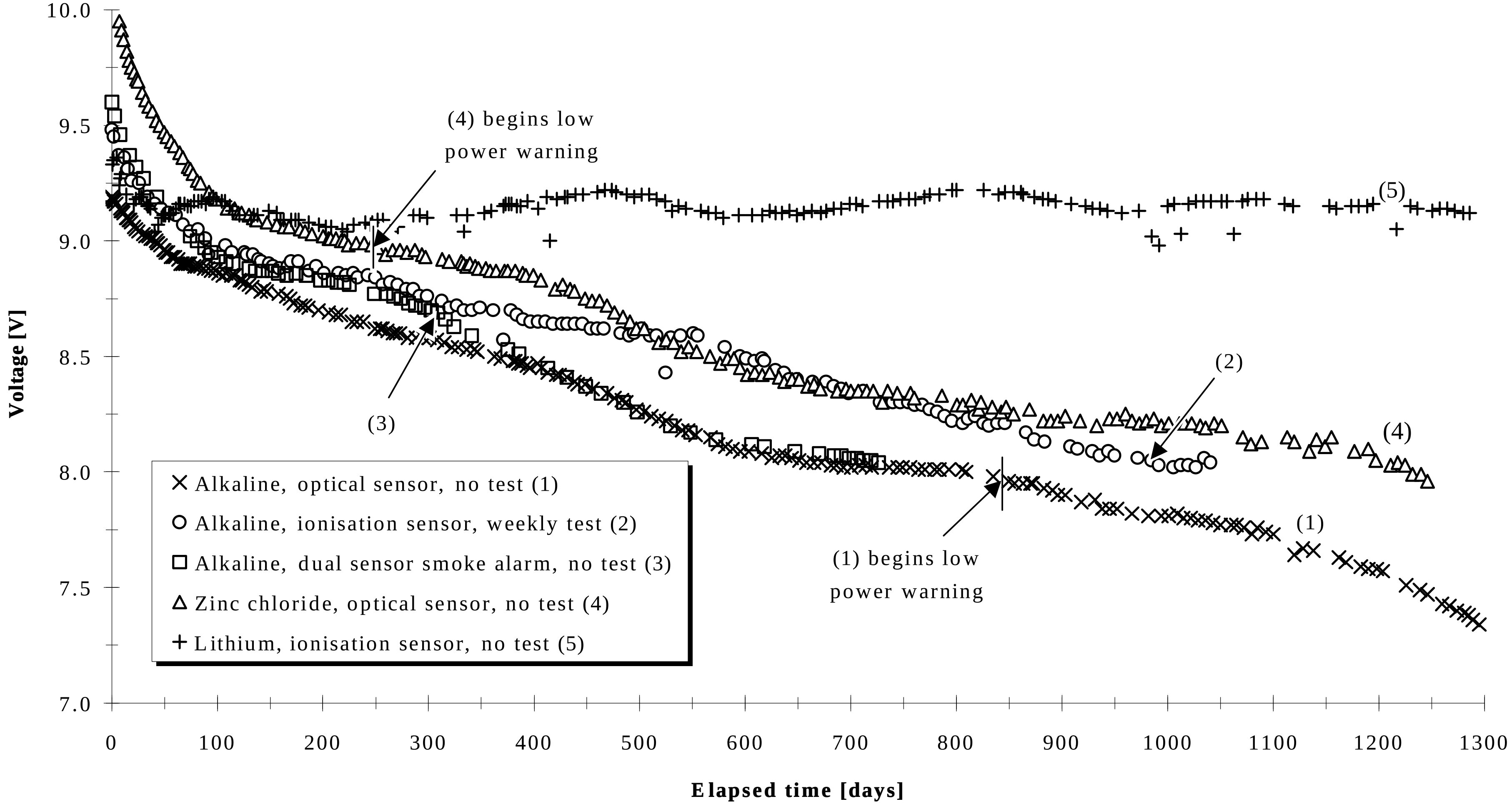

Figure 1. Primary cell voltage discharge curves.

By the eighth discharge cycle the voltage soon falls to a level at which the low power warning is given however this period extends further than the earlier discharge cycles. Similar behaviour was recorded in several smoke alarms having a NiCd backup supply.

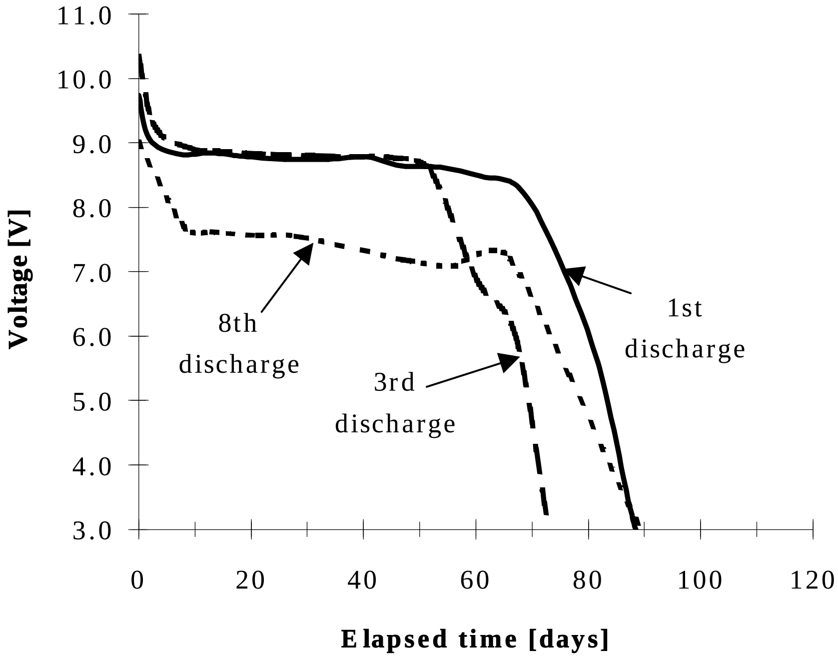

Figure 2. Voltage discharge curves for a NiCd backup source.

From these results it is clear that the NiCd cells will exhibit a memory effect. The repeated discharging and recharging the cells leads to a reduced capacity. However these tests present a demanding requirement on the performance of the cells that may not be encountered in the field. Where smoke alarms using a NiCd backup source were continuously connected to the mains supply it was found that the capacity of the cell was not affected.

2.3 Super-capacitors

Figure 3 shows the voltage discharge curves for optical sensor and ionisation sensor smoke alarms with super-capacitor backup energy source. Both devices show similar profiles and on average give eight days backup until the low power warning is given.

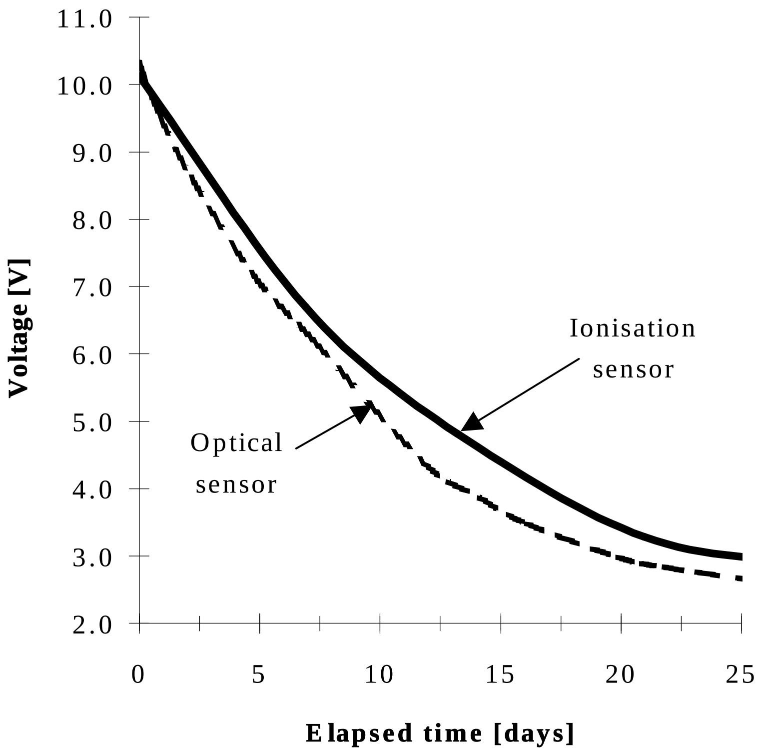

Figure 3. Voltage discharge curves for super-capacitor backup sources.

During the testing it was noted that several devices containing super-capacitors did not fully charge during installation and one device failed during the test procedures. These faults were identified with early models and the manufacturer has since resolved these problems. The majority of the smoke alarms using the super-capacitor backup supply (including devices that were subjected to repeated discharge cycles) functioned well and users in the field report acceptable performance from their installations.

2.4 Rechargeable lithium

The performance of the rechargeable lithium cell is shown in *Figure 4*. The first discharge of the cell gave approximately 265 days of backup capacity. However by the sixth discharge cycle the capacity had fallen to only 6 days. It is clear from these tests that the capacity of the rechargeable lithium cell deteriorates significantly when it is repeatedly discharged and recharged. As with the NiCd cells, these tests present a demanding requirement on the performance of the cell.

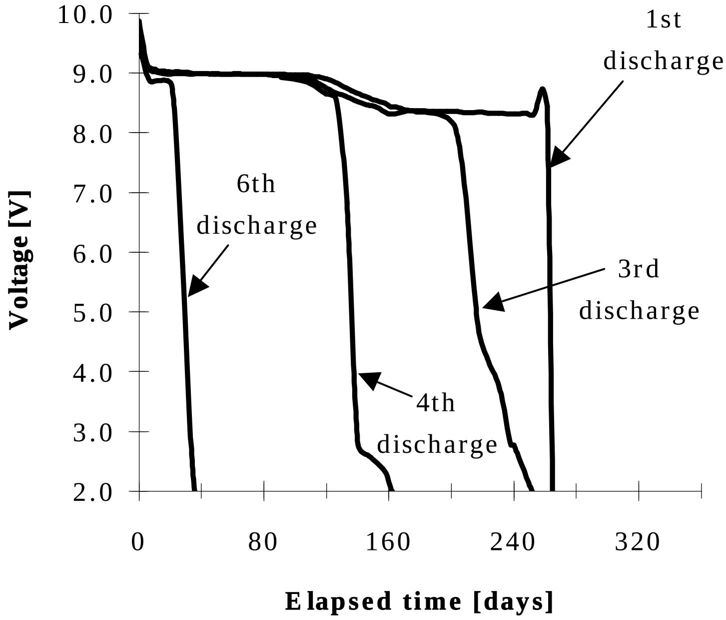

Figure 4. Voltage discharge curves for a rechargeable lithium backup source.

2.5 Summary of results

The results of the standby mode tests are summarised in Table 1. What is somewhat surprising is the length of time that primary cells are able to supply a smoke alarm in standby mode. These extended periods of operation have meant that complete discharge times of the sources cannot be reported here. The times quoted for the NiCd and rechargeable lithium cells are typical values since their performance was found to vary with each discharge cycle.

3 Conclusions

Primary cell batteries provide an effective backup supply to mains-powered smoke alarms. The standby capacity of a cell has the potential to extend for several years depending on the particular technology. The use of primary cells may not eliminate the problem of battery removal and they may need to be replaced if they become sufficiently discharged.

Backup power source	Specifications	Time to low power warning [days]	Time to sounder power failure [days]	Time between low power warning and sounder failure [days]
Zinc chloride cell	Optical sensor, no weekly test	245	> 1250	> 1005
Alkaline primary cell	Optical sensor, no weekly test	855	> 1295	> 440
	Ionisation sensor, 5 second weekly sounder test	> 1040	-	-
	Optical/ionisation sensor, no weekly test	> 725	-	-
Lithium primary cell	Ionisation sensor, no weekly test	> 985	-	-
Nickel cadmium (1)	Optical sensor, no weekly test	148	160	12
	Ionisation sensor, 5 second weekly sounder test	68	78	10
Super-capacitor	Optical sensor, no weekly test	7 ½	12	4 ½
	Ionisation sensor, no weekly test	8 ½	16	7 ½
Rechargeable lithium (2)	Ionisation sensor, no weekly test	253	265	12

- No data available

(1) Typical values before memory effect

(2) Initial value before degradation

Table 1. Summary of backup power source standby mode performance.

The potential memory effect and the disposal difficulties of NiCd cells place some limitations for their use as backup power sources for smoke alarms. They are more suitable in applications where disconnections from the AC supply are expected to be infrequent. The super-capacitor backup power source is suited to situations where expected periods of disconnection from the mains supply will be relatively short. They can be repeatedly discharged and recharged without any memory effect. Rechargeable lithium cells have a standby capacity somewhere between a typical NiCd cell and an alkaline cell. Although they reportedly do not suffer from the memory effect, the results presented in this paper show that their performance does degrade with repeated discharge cycles. Compared to the primary cells, all of the rechargeable backup sources have a much shorter time between the onset of the low power warning and the voltage falling below the sounder operation threshold.

New backup power source technologies are being developed and current technologies are being advanced. Some of these developments may find their way into future designs of smoke alarms with potential improvements in their backup energy source performance.

4 Acknowledgements

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