Fire safety engineering guideline for informal settlements

Towards practical solutions for a complex problem in South Africa

Editor: Richard Walls

Authors: Richard Walls, Antonio Cicione, Robyn Pharoah, Patricia Zweig, Mark Smith and Danielle Antonellis

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Executive Summary

Informal settlements are growing rapidly, and in Africa they are likely to double in size within the coming few decades. Informal settlements (IS) (also known by names such as slums, ghettos, favelas and shantytowns) are typically dense, and people's homes are built from highly combustible materials. Hence, when a fire breaks out it can spread rapidly, leaving thousands homeless. Every year in South Africa fires are affecting large numbers of people, costing municipalities millions of rands (ZAR), and are severely hindering the upliftment of the poorest in our communities.

This guideline seeks to provide a holistic approach to improving fire safety for communities. It is important to realise that this complex problem can only be improved by a multi-sectoral response addressing various issues such as: reducing the risk of ignition, providing early warning systems, having community involvement, having well-resourced and well-prepared fire departments, reducing the combustible nature of homes, and many other similar factors.

The audience of this report is broad in that it seeks to assist fire departments, local municipalities, national government, engineers, town planners and non-governmental organisations involved in IS fire safety. This work initially provides an understanding of communities living in settlements, as often interventions overlook the daily reality of these people which leads to interventions being ineffective. Fire behaviour, fire spread and fire safety engineering is then discussed, and it is shown how this can be applied to ISs. This is done to dispel many common myths, and to show what can, and can't, improve fire safety. To understand IS fire incidents a timeline of a typical fire incident is provided, along with a case study on the 2017 Imizamo Yethu disaster. Many interventions, strategies and devices are discussed, looking at what could be adopted to improve fire safety. It is important to realise that a basket of solutions is typically needed, and a single intervention may have a very limited impact. A list of tasks that communities can undertake before, during and after a fire incident provides a useful resource for organisations working with communities.

Ultimately there is no easy solution to this problem. However, through a concerted, evidence-based approach significant fire safety improvements can be made to help the poorest in our land.

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FOREWORD: Western Cape Department of Human Settlements

In South Africa around 15 - 30 informal settlement fires occur daily, accounting for at least one death per day. Millions of rands are spent annually on fire departments, disaster management, emergency response, hospitalisation of burn victims and providing emergency relief. In most informal settlements, these fires take place mainly late at night and while people are asleep, therefore inhabitants are at their most vulnerable state. It is often the most destitute in our society that is affected by these fires, costing them their prized possessions or worse, their lives.

Fires in informal settlements are undeniably increasing. In the main, these are due to dwellings being built using highly flammable materials, the use of open flame appliances and electrical hazards. These fires are also linked to people knocking over paraffin stoves and candles. In light of this, the Western Cape Department of Human Settlements saw it fit to support this project by Stellenbosch University's Fire Engineering Research Unit in the Department of Civil Engineering, one of the pioneers in the country with a quest to study the complexities linked with fire hazards and safety in informal settlements.

This study seeks to provide a holistic approach to improving fire safety for communities in informal settlements. The Guideline not only reflects the risks people in informal settlements face but also the interventions required to help manage and reduce these risks. The Department acknowledges the recommendations in this report and intends to explore means with which to embed these in its work in informal settlements in the province. We anticipate that this Fire Safety Guideline will also serve as a useful resource for fire departments, municipalities, provincial and national government departments, town planners and non-governmental organisations working within informal settlements.

I hope this document will stimulate the promotion of fire safety in informal settlements in the Western Cape and contribute to efforts to build a safer and more humane world.

Jacqueline Samson
Head of Department: Human Settlements

FOREWORD: Lloyd's Register Foundation (co-funder of research)

The Lloyd's Register Foundation is an independent global charity that supports research, innovation, and education to make the world a safer place. To achieve our mission we seek out willing collaborators who share our strong social purpose and then build coalitions that deliver long term impact for people and property across the planet. Our work with Stellenbosch University in establishing the Fire Engineering Education for Africa (FEEFA) programme is a shining example of this charitable mission being realised. The resources and expertise that will be produced from this partnership are the first of its kind on the African continent, and will certainly create meaningful change for thousands of families across South Africa and beyond. The programme truly is a remarkable success story of how we can work together to make the world a safer place.

Professor Richard Clegg, FREng, FRSC
Foundation Chief Executive: Lloyd's Register Foundation

The opinions expressed in this publication are those of the authors. They do not purport to reflect the opinions or views of the funders or its members.

From the editor

Poverty is unfortunately a sad part of human existence, and we should not think that informal settlements (IS) will go away anytime soon. As ISs rapidly grow across the world we need to deal with this social challenge as best as we can, realising that our response will never be perfect. However, I am positive that progress can be made, circumstances can be improved and through a better understanding of fire safety engineering we can try follow many countries who have been experiencing a progressive decrease in fire losses and deaths, rather than our current increasing trend. Ultimately, as we seek to help (and learn from) those living in poverty we can know that "whoever is kind to the needy honours God" (Prov. 14:31).

This book and project would never have come about had it not been for support from the Western Cape Department of Human Settlements (WCDHS). We would like to thank the many people at the WCDHS who have facilitated this project and made it possible, especially Eugene Visagie and his colleagues Amarone Nomdo, Pamela Masiko-Kambala and David Alli. Also, we would like to thank the Lloyd's Register Foundation for the co-funding received for this project under the "Fire Engineering Education for Africa" grant.

Many people have contributed to our efforts over the past years, and made the research which this book is based upon, possible. We would like to thank the Breede Valley Municipality (especially Chief Fire Officers Josephus Pretorius & Theo Botha) and the City of Cape Town for assistance in full-scale fire testing over the years; the Western Cape Disaster Management Fire & Rescue Services (WCDMFRS) for assistance in a wide variety of aspects (especially Mr Rodney Eksteen for significant early support and helping get us established); the University of Edinburgh (especially Dr David Rush) and the EPSRC for the work done though the IRIS-Fire project; Oklahoma State University for assistance since the start of our work; the Cape Higher Education Consortium & Western Cape Government (CHEC-WCG) through funding received; and the many students and colleagues who have contributed research that has become part of this work (such as Stefan Löffel, Natalia Flores Quiroz, Vignesh Narayanan, Gerhard Olivier, Dr Charles Kahanji and Dr Nico de Koker, along with multiple undergrad students).

As authors we are grateful to the people who peer-reviewed this document and provided many helpful suggestions such as: Astrid Wicht (People's Environmental Planning (PEP)), Eugene Visagie & Amarone Nomdo (WCDHS), Marlu Rust (WCDMFRS), all my co-authors, and Vignesh Narayanan & Natalia Flores Quiroz (Stellenbosch University).

Wishing you happy reading and a safer future

Prof Richard Walls,
Fire Engineering Research Unit, Stellenbosch University (FireSUN)

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1. Introduction

Richard Walls

Fire Engineering Research Unit, Stellenbosch University (FireSUN)

Informal settlements (IS) in South Africa are growing rapidly and becoming denser. In South Africa an IS is defined as an "unplanned settlement on land which has not been surveyed or proclaimed as residential, consisting mainly of informal dwellings (shacks)"[1]. Due to the inherently flammable nature of homes in settlements, and the many ignition sources such as paraffin stoves, overloaded electrical sockets and candles, unwanted fires happen often and can become big. In the past as many as 10,000 people have been left homeless in a single fire. Figure 1-1 is an aerial image of the aftermath of the 2017 Imizamo Yethu fire in Hout Bay, showing how large areas can be devastated by fires in a matter of minutes or hours. Whilst the number of IS homes is growing, the number of informal homes behind formal structures, called "backyard" dwellings, is also increasing rapidly.

Figure 1-1: Aerial image of the Imizamo Yethu informal settlement after the large 2017 fire (Image used permission by Bruce Sutherland, City of Cape Town)

Chapter citation: Walls, R. (2020), "1. Introduction", in Walls, R. (Ed.), *Fire Safety Engineering Guideline for Informal Settlements: Towards Practical Solutions for a Complex Problem in South Africa*, FireSUN Publications, Stellenbosch, pp. 1–8.

The number of IS fires is ever increasing. Figure 1-2 shows the number of informal settlement fires reported by fire departments in between 2003 and 2018. It can be seen that from around 3000-3500 fires in 2003 to 2006, we now have around 5500 reported fires per year. This number excludes (i) the many fires that residents extinguished themselves, such that the local fire station was not notified, and (ii) data from fire departments who did not submit their data. Furthermore, Figure 1-3 shows the number of fatalities reported by fire departments in 2018, where of a total of 586 deaths, 289 of these were in informal settlements. This means that almost 50% of all fire related deaths occur in ISs or informal structures (i.e. backyard dwellings), whereas 18 to 33% of the population reside in such households (estimates vary).[2] Furthermore, the total number of deaths reported by fire departments is likely to be a significant underestimation, as the aforementioned statistics are only for deaths at the location of the fire. If someone is injured in a fire and dies in hospital later this is not included in the statistics. As an example, mortuary data from 2011 showed that 2,243 people died from 'exposure to smoke, fire and flames'.[3] In the same year, the number of deaths reported by fire departments was 410, meaning that the mortuary data is around 5-6 times higher.

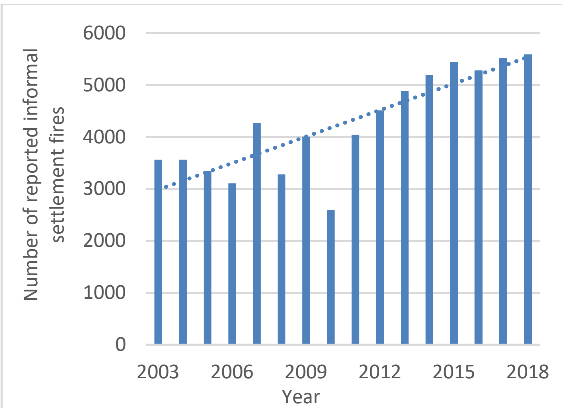

Figure 1-2: Number of reported informal settlement fires between 2003 and 2018 in South Africa (data based on [4])

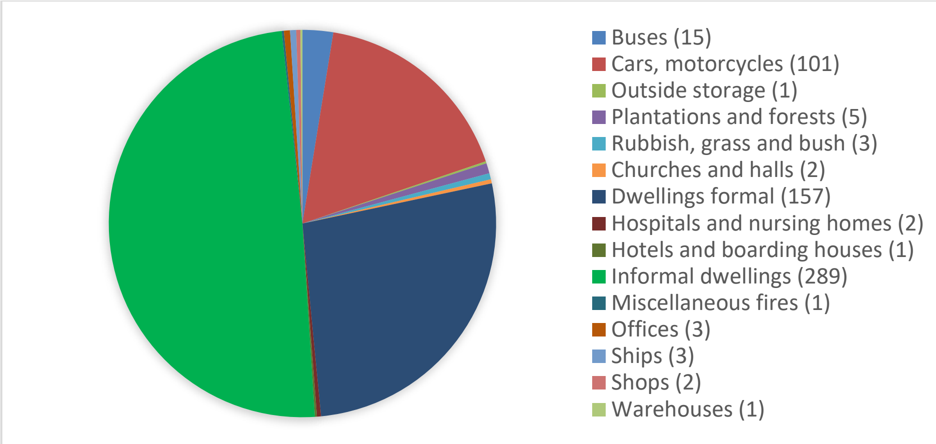

Figure 1-3: Number of fatalities in different types of fires in 2018 (data based on [4], with the number of incidents shown in brackets)

The above statistics indicate that around 15 - 30 IS fires occur daily, accounting for at least one death per day. Millions of rands are spent annually on fire departments, disaster management, emergency response, hospitalisation of burn victims (a very high cost which is often forgotten), providing emergency relief, lost production time for workers affected, and similar factors. It is often the poorest in our society affected by these fires, costing them the totality of their possessions or worse, their lives. However, IS fires are not only a challenge in South Africa, but all over the world, and settlements are growing fast.[5,6] UN Habitat estimates that by 2050 there will be 1.2 billion informal settlement dwellers in Africa alone.[7] Hence, informal settlements are here to stay, and they will grow. But what can we do about the fire problem?

1.1 What is this guideline?

In many developed countries, the number of deaths due to fires has decreased significantly in the past decades. Through the application of building codes, municipal enforcement, fire department response, public education and improved construction materials, the number of fires, and the size of fires, has been reduced.[8] Building codes and standards are often referenced as the first line of defence for fire safety. But, when we consider how to apply such fire safety developments to ISs, it begs a challenging question – what building codes and standards can be enforced in an area that inherently does not comply with any codes and standards? An informal settlement is just that – informal, i.e. not regulated and controlled by building standards.

The ideal situation would be to alleviate informal settlements by providing people with safer code-compliant homes. Access to affordable, safe housing is critical to ensure sustainable development and poverty alleviation. However, in reality demand exceeds supply, resources remain limited, and populations are growing. Given the dire reality, we need to improve circumstances where possible. Hence: *this work aims to improve informal settlement fire safety through a holistic understanding of (a) the science of fire behaviour, (b) the application of fire safety engineering, (c) an understanding of the social realities of inhabitants, (d) an acknowledgement of the complexity of addressing the problems in settlements, and (e) a realisation of the limited resources available. We want to know: How can we maximise the limited resources available?* The focus is on preparation/risk mitigation, rather than response. Undergirding the proposals in this document is the application of fire safety engineering. Ultimately we, as a society, will pay for the cost of fire safety, the question is simply: will we pay a lower amount before an incident through good preparation and risk reduction, of will we pay a higher amount after an incident through response and relief efforts, and lives lost?

The audience of this report is broad in that it seeks to assist fire departments, local municipalities, provincial and national government departments, engineers, town planners and non-governmental organisations involved in IS fire safety.

1.2 A framework for understanding fire safety

Figure 1-4: Framework for addressing informal settlement fire safety (adapted from [9])

Consider Figure 1-4 which is a framework to assist in understanding the many ways that IS fire safety can be improved. When addressing fire safety, it is vitally important to understand that a number of issues have to be addressed, and so the framework is broken up as follows:

- Fire ignition / risk of ignition – If we can reduce the number of fires that are started we can reduce the number of people affected. For this we need to understand what causes fires, human behaviour leading to accidental fires, and what can be done to prevent this.

- Passive fire protection – Once a fire has started we want to keep it in as small an area as possible by preventing it from spreading. This is known as containment, or compartmentation in formal buildings, and involves the use of suitable construction products, improving area layouts and for settlements can involve providing spaces between dwellings. Such aspects can all be considered as passive protection, as they require no human or mechanical/electrical intervention. Passive fire protection is typically used to provide a safe means of escape in formal buildings (e.g. stairway or corridor protected by fire resisting construction). While the same approaches may not be feasible in informal settlements, safe means of escape both to the outside of buildings and to remote outdoor assembly points do need to be considered.

- Active fire protection – Anything that requires a human, device or piece of equipment to be activated once a fire starts can be considered active fire protection. This involves fire departments, products for suppressing fires, community response teams and detection systems that can alert people about the existence of a fire.

- Community awareness, response and engagement – People living in informal settlements understand the risks and vulnerabilities of their community best. They must be as fully integrated and empowered as possible to participate in decisions that affect them. Furthermore, any fire safety initiative in ISs will be unsuccessful, or much more difficult to implement, if it does not involve the local community. Residents are the first responders to most fires. They play a critical role in incipient firefighting, notifying the fire department and other residents, and supporting evacuation. The community can work together to prevent fires and improve fire response. Community engagement and participation processes for projects are critical to ensure co-design and co-ownership of upgrading projects and any fire safety intervention.

We ultimately seek to provide an Integrated Fire Safety Solution or Strategy for each community, but that relies on a number of factors. For instance, if every community member in an area was provided with a fire extinguisher (active protection) it could assist in putting out many small fires. However, once a fire becomes larger than a certain size fire extinguishers may become ineffective and rapid spread will still occur if there is continuous fuel bed (i.e. combustible homes) due to a lack of compartmentation. If every home was provided with properly installed fire protection boards on their walls and roofs (passive protection) it may help to reduce the speed of fire spread, but would not reduce the chance of a fire occurring. If electricity is provided to an area and less candles and paraffin lamps are used (fire prevention / risk of ignition), but there is no fire department available then when a fire has started it can become large, and will continue to burn until all the homes are gone (and electrical fires can still occur). Hence, *Integrated Fire Safety* is required and this should address (a) active protection, (b) passive protection, in addition to safe means for escape, and (c) fire prevention / risk of ignition. A balanced approach is needed to improve fire safety, and providing only one aspect will often have limited impact.

When developing fire safety strategies it must also be appreciated that multiple factors may make inhabitants more vulnerable to the effects of fire, and a host of different people groups with different challenges exist in each community. Vulnerabilities to be considered include disabilities (physical, sensory, cognitive) or age (children, elderly) which can hinder evacuation, having no support structure which prevents post-fire recovery, cultural and language diversity and even being a foreigner as that may prevent an individual from getting certain support.

1.3 Overview of this work

Initially the IS context is explained, to highlight the problem faced, and policies around them. Thereafter, the basics of fire safety engineering and fire science are outlined. This section is important as it provides the technical basis for any intervention employed. A timeline of fire incidents is presented to help understand how large urban fire disasters unfold, and what can be done to reduce the impact of them. The 2017 Imizamo Yethu disaster is discussed as a case study to illustrate how large and complex incidents can be, and also how the interventions proposed in this document, may, or may not, perform in such instances. Thereafter, many different interventions that can be employed are discussed. The challenges and benefits, or advantages and disadvantages, of each intervention is presented. A list of ways that inhabitants can improve fire safety before an incident, and actions to carry out during or after incidents, is presented. Details regarding informal "backyard" dwellings constructed in formal areas are provided. The work is applied and simple recommendations made in the final chapter, along with a list of areas needing further research.

It must be emphasised that this work is a First Edition and will need to be updated and improved as time goes by. Internationally there has been limited effort to create a practical document on fire safety engineering in informal environments, so this work provides an important foundation for developing this field. It is hoped that as solutions are tested and lessons are learned from future fires, the recommendations made in this work can be enhanced, improved and even corrected.

It should be noted that there are many existing documents that provide additional insight on topics in this work such as: a framework for fire safety in informal settlements focussing on the disaster cycle,[10] performance-based fire engineering design,[11] fire dynamics,[12] community engagement,[13] and much more. These can be consulted for details beyond the scope of this work. This work only briefly introduces many complicated concepts.

For suggestions on how to improve this document, details on interventions which have been tried and found to be successful or not successful, or any feedback please feel free to email fire@sun.ac.za with details.

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2. Informal settlement context in South Africa

Robyn Pharoah & Patricia Zweig

Research Alliance for Disaster & Risk Reduction (RADAR), Stellenbosch University

This chapter helps provide the political and social context of informal settlements (IS) in South Africa. Before trying to assist communities, it is important to understand how they operate, the nature of existing leadership structures, processes of engagement, government policies and many other factors. Any organisation seeking to assist should engage communities to obtain their input and perspectives, and involve them in all aspects of the project.

2.1 What do we mean by an informal settlement?

An IS refers to unplanned housing (along with associated shops, crèches, etc.), typically constructed from sheets of corrugated iron (galvanised steel), wood and other recycled materials, as shown in Figure 2-1. Informal settlements are generally characterised by chronic levels of poverty, overcrowding, or deficient basic services, and a lack of tenure.[14] Many people are unemployed or under-employed and experience food insecurity. In many areas social problems such as gangsterism, alcohol or drug abuse and crime are prevalent. Many ISs are technically illegal, whilst for others a local authority has provided them with rights to occupy the land. Organisations such as UN-Habitat emphasise that security of tenure is an important component of the definition of an IS. Residents are unlikely to upgrade their homes when they fear eviction. Most ISs do not initially have access to basic services, but in South Africa, local authorities are mandated to provide basic water and sanitation infrastructure and refuse removal, and are increasingly rolling out electricity infrastructure. Settlements fall outside of building regulations that might reduce the risk of fire and have limited or no access to piped water, fire hydrants or other infrastructure that could help in putting out fires. To illustrate the shortfall in infrastructure provision, according to the 2011 Census 68% of IS households use shared toilet facilities, 6.8% use the "bucket system" for human waste and only 43% of households had access to electricity.[15]

Chapter citation: Pharoah, R. and Zweig, P. (2020), "2. Informal settlement context in South Africa", in Walls, R. (Ed.), *Fire Safety Engineering Guideline for Informal Settlements: Towards Practical Solutions for a Complex Problem in South Africa*, FireSUN Publications, Stellenbosch, pp. 9–22.

Figure 2-1: (Left) A variety of unregulated construction methods and materials are utilised to build informal dwellings, and (Right) flammable synthetic materials lining a home, positioned against electrical equipment.

Most dwellings lack foundations and are poorly insulated against the elements, making them extremely cold in winter months and unbearably hot in the summer. Informal dwellers will usually insulate their homes on the inside using sheets of cardboard, timber or any other materials they can utilise, and water-proof their roofs with plastic and other materials. Construction materials may be purchased from local suppliers and from IS businesses selling new and used materials. Informal economic activities relating to construction, supply chain and material sourcing, installation and other activities are important, with various artisans and businesses being active in this sector. Building materials that can be sourced in the immediate vicinity of ISs are commonly utilised.

2.2 The origins of informal settlements in South Africa

In South Africa, informal settlements are a legacy of the apartheid regime's 'separate development' policies, and continued inequalities in the distribution of wealth in the post-apartheid era. Under apartheid, stringent laws restricted the movement of people of colour and denied them rights to settle permanently in urban areas. As a result, very few houses were built to accommodate them, leading to the critical shortage of housing that continues today.

Today, the growth of populations both through natural population growth and in-migration continues to outpace available housing supply. Of the 16.9 million households in South Africa, 13 % live in informal settlements with a further 4% living in "backyard shacks".[16] In the Western Cape, one out of every seven households lived in informal dwellings in 2001, but this had increased to one in five households in 2016[16]. In the City of Cape Town alone, the largest metropole in the Western Cape region, there are currently over four hundred informal settlements, varying in size from a few dozen dwellings to several thousand.

In many areas, the distinction between 'formal' and 'informal' neighbourhoods is becoming increasingly blurred. In many low-income formally planned suburbs, there are increasing numbers of informal ('backyard') dwellings and Wendy houses, as discussed in Chapter 7. At the same time, 'in-situ' upgrading of ISs is contributing to a steadily increasing number of more permanent formal homes and businesses.[13]

2.3 Key government policies

There are a range of legislative and policy documents relevant to informal settlements on the national, provincial and municipal level. All acknowledge that informal settlements are, and will remain, a feature of the South African landscape for the foreseeable future, but promote formalisation and improving conditions in informal areas.

South Africa's Breaking New Ground policy was incorporated into the Housing Code in 2004. It calls for the eradication of informal settlements, preferably through phased in-situ upgrading. The National Housing Code of 2009 from the Department of Human Settlements (DHS) promotes the upgrading of ISs, and emphasises aspects such as the need for community members to be part of this process, along with the provision of security of tenure.[17] The National Upgrading Support Programme (NUSP) of the DHS seeks to provide technical assistance and capacity development to provinces and municipalities who act to implement the work.[18] Such programmes also focus on in situ upgrading of homes, rather than the relocation of residents, and this aligns with the National Development Plan (NDP), 2030. The relocating and displacement of communities can have a significant negative impact.

In 2016, the Government of the Western Cape developed the Informal Settlement Support Programme (ISSP) which is guided by the Informal Settlement Strategic Framework (ISSF).[19] This aims to ensure that poor people will have a better and secure place of residence by 2030. It calls for:

- liveable neighbourhoods that allow people to inhabit the settlement with dignity and security;

- integrated neighbourhoods that offer a wide variety of public services to people from different social, cultural and economic backgrounds;
- vibrant neighbourhoods that have a thriving socio-economic environment, underpinned by good quality urban infrastructure, public space and services;
- resilient neighbourhoods that can withstand natural shocks and stresses, such as flooding and climate change.

In Cape Town, the City of Cape Town's Integrated Human Settlements Plan 2012-2017 sought to plan and manage the consequences of urbanisation proactively and sustainably. It outlines three core responses to informal settlements, including (a) the continued roll-out of shared services, (b) incremental upgrading, with an emphasis on re-blocking, and (c) providing temporary housing for families in need of emergency housing.

More recently, in August 2019, the City of Cape Town adopted its first ever City Resilience Strategy.[20] The Strategy was developed through extensive stakeholder engagement with 11,000 Capetonians, thematic experts from CBOs (community-based organisations), NGOs, business, academia, and various spheres of government. Fire was identified as a prioritized shock affecting Cape Town – including informal settlement fires and wildfires. There are several agreed actions which relate to fire safety in informal settlements, such as to:

- Implement innovative solutions to reduce the devastation of fire in informal settlements;
- Explore alternative, innovative and financially feasible mechanisms of service delivery in informal settlements which are acceptable to local residents;
- Co-design for informal settlement upgrading projects with local residents;
- Develop 'build back better' protocols for infrastructure damaged in shock events;
- Expand the women and girls resilience program.

2.4 Backyard Dwellers

Chapter 7 provides a discussion on fire engineering aspects of backyard dwellings, applying the discussions throughout this guideline to them. While the problem of informal settlement fires is well known, there is some evidence to suggest that backyard dwellings built on formal housing plots are just as prone to fire outbreaks, and such fires can be more lethal. For example, research in Langa, in Cape Town[21], revealed high numbers of fires in informal dwellings within formally planned areas. There is also recent anecdotal evidence of higher mortality rates due to fires among backyard dwellers than those living in informal settlements. This may be influenced by the fact that backyard dwellers can more easily become trapped when trying to escape between formal houses and boundary walls, relative to evacuating in an informal settlement.

South Africa's 2011 census showed that the number of households living in backyard dwellings had increased by more than half (55%) from 460 000 to 713 000 since the previous census in 2001.[22] Almost every city has seen an increase in the number of households living in backyard dwellings, rising by 129% in Cape Town, 117% in Tshwane and 58% Johannesburg – South Africa's largest cities.[22] These backyard dwellings are generally built without planning permission to house relatives or to rent out to generate income. While they can be small brick and mortar rooms, more often they are makeshift shacks made of the same rudimentary and highly flammable materials like those found in informal settlements.

Backyard dwellers have other things in common with informal settlement dwellers, such as generally crowded living environments, use of unsafe energy sources such as paraffin and candles, or rudimentary electricity connections to the main house, as well as inadequate access to water sources. Thus, the risk of fire is high among backyard dwellers who lack the social capital available to informal settlement dwellers for collaborative firefighting efforts, hidden behind the fences and gates of formal houses where fires are less easy to detect and just as difficult to respond to.

2.5 How significant is the problem of fire in the hierarchy of risks?

People living in informal settlements face a range of hazards. In addition to fires that occur throughout the year, most experience flooding during rainy months; public health risks related to poor sanitation and hygiene and pollution; and high levels of unemployment, alcohol and drug abuse contribute to crime and violence. Community-based risk assessments conducted in dozens of informal settlements in the Western Cape since 2008 have demonstrated how informal dwellers increasingly prioritise other risks above fires. In hazard prioritization exercises conducted in two informal settlements in Mfuleni, Cape Town (see Figure 2-2 below), community members identified their most pressing concerns, in order of concern, revealing that fire was low on their list. This demonstrates why, given their limited resources, informal settlement dwellers tend to address more immediate concerns (e.g. health or crime), investing little time or effort to reducing the risk of fire.[2]

Figure 2-2: In hazard identification exercises undertaken in two informal settlements residents listed and prioritised perceived local hazards, demonstrating how fire is generally not their greatest concern.

Although informal households can become quite good at coping or managing some of their risks, they are challenged to reduce them sustainably or adequately. Responses to some hazards may drive up the risk of others. For example, using plastic sheeting to prevent water from entering may increase the amount of fuel for fires, and enhance fire spread rates. There are also often limited incentives to invest in risk reduction. For example, in Cape Town, many people living in informal settlements come from the Eastern Cape. Their informal dwellings are generally considered only temporary and 'a means to an end'. Therefore, few households invest resources in making their homes more resilient to the hazards encountered, preferring to invest their resources in their homes and families in the Eastern Cape.

2.6 The fire-risk landscape in informal settlements

Many factors influence the risk of fire in ISs. These are both structural and behavioural. Sources of ignition are plentiful. Although local government is rolling out electricity, many informal settlements still do not have formal access to the grid and rely on more dangerous energy sources, such as paraffin, open fires or gas for cooking and heating, and candles for lighting. In unelectrified settlements, households also often run connections from infrastructure in areas connected to the grid, or may have extension cords supplying power from homes with metered connections. In this report the term "informal electrical supplies" will be used to describe all non-code compliant electrical installations, which encompasses situations such as those discussed above namely: illegal electrical connections to municipal infrastructure, illegal connections to other residents' homes, and legal extension cords connected to a neighbour's house who has a formal metered connection. The latter may not necessarily be illegal, but in many cases is still dangerous. These 'spaghetti wires' criss-cross settlements, over roofs and at ground level, as shown in Figure 2-3. These can spark, causing fires, but also prevent fire trucks and emergency services from entering when fires occur. See Section 6.5 for further discussion on these issues.

Figure 2-3: A view an informal areas showing various electrical connections that are a significant problem for fire safety

Fires are also linked to endangering behaviour. For example, in a survey of 856 households in TRA informal settlement in Wallacedene, in Cape Town,[23] those interviewed reported that fires were most common over the weekend, and late at night, or during the sleeping hours. Three out of every four households (77%) attributed this to alcohol-related behaviour, including people knocking over paraffin stoves and candles or falling asleep with a pot on the stove or something burning. On weekends, people also do their household chores and sometimes leave stoves unattended while they fetch water or are distracted by chatting to neighbours. Children are sometimes also left alone when their parents go out to carry out chores, work, or socialise, with fires starting when children cook for themselves or play with matches (see Figure 2-4). Single parents may often have to leave children alone.

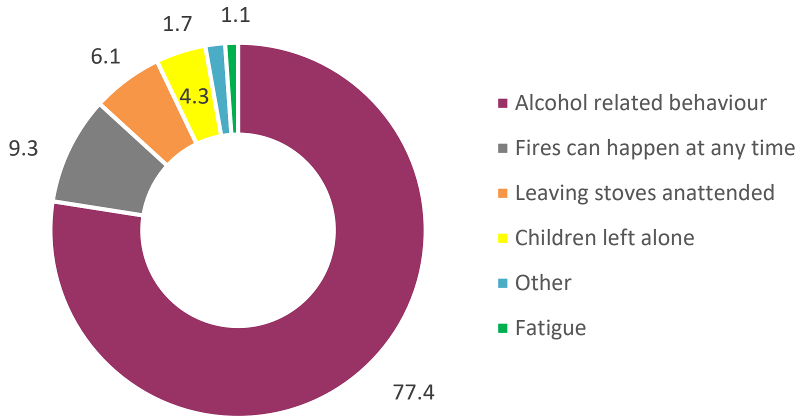

Figure 2-4: Perceived reasons for the prevalence of fires on weekends in the Wallacedene TRA Settlement (n=856) [23]. Values provided are percentages.

Several physical factors increase the risk of fires. Dwellings are usually built using highly flammable materials, with cardboard often used to insulate houses from heat and cold. Settlements are often overcrowded and houses densely packed. Due to the lack of space, stored materials are often wedged in the spaces between dwellings or kept on the roof. Typically, these include building materials such as pieces of wood and window frames, which provide fuel for fires and help them spread from one dwelling to another. Broken electronic goods, tyres cardboard boxes and various other materials can also be found stored between dwellings.

There are also barriers impeding escape when fires occur. For example, many informal settlement dwellings have burglar bars on windows and security gates, which can make it harder to get out of dwellings. In the Wallacedene survey, almost half (47%) of those interviewed reported that it would be difficult to get out of their front door during a fire, owing to gates or padlocks, with an additional 15% reporting that items, such as furniture, would also make it difficult to even reach their door, as shown in Figure 2-5. For further discussion on this topic refer to Section 6.4.5.

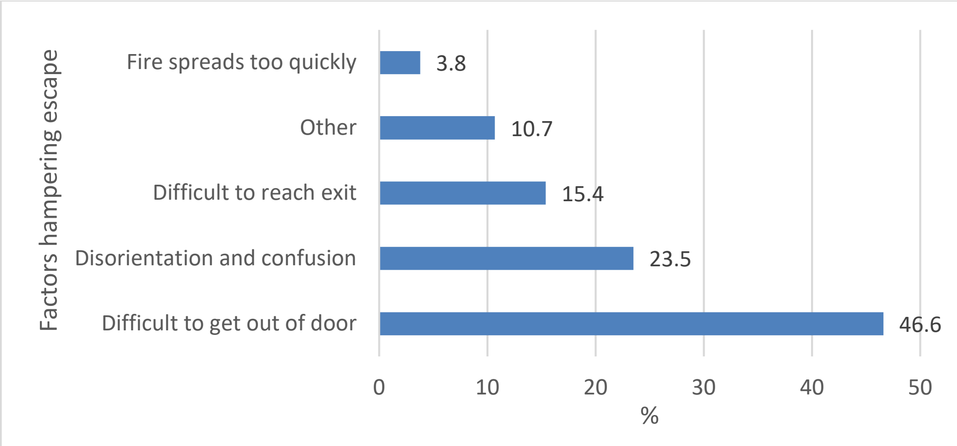

Figure 2-5: Factors making escape difficult in the event of a fire in the Wallacedene TRA Settlement (n=856) [23]

Once fires do occur residents are often desperate to ensure that they do not lose their piece of land, so will start rebuilding immediately. This can make post-fire enumeration and upgrading efforts difficult as members will erect homes before improved layouts can be developed or implemented. Hence, post-fire reconstruction periods should not be viewed as a means of easily implementing any projects requiring planning, community engagement or general coordination.

2.7 Working to reduce fire risk in informal settlements

2.7.1 Key challenges associated with working in informal settlements

It can be challenging to work in informal settlements due to their dynamic nature. The fluidity of informal environments can be particularly difficult. People constantly come and go, moving from one place to another in search of work opportunities. Household composition also changes frequently as a survival strategy. Households with one or more breadwinners will often accommodate extended family members struggling to survive elsewhere. Children, in particular, move from one family unit to another to ensure that they are fed and/or can attend a nearby school or clinic. Thus, community engagement needs to be ongoing, to accommodate the typically dynamic nature of informal areas.

Intra-community dynamics can also be complex. Although this term is often used to refer to people living in one area or settlement, the term 'community' implies togetherness and a positive bond among people. However, experience shows that there is no such thing as a homogenous community with shared interests and values – regardless of where people live. Even within relatively small settlements, there are hierarchies, power-dynamics and competing agendas, as well as cultural, language and gender differences, and dominant or powerful voices can drown out more marginalised ones. This makes it important to try and understand the dynamics within communities and to always identify whether some interests are being neglected.

2.7.2 Tips for engaging settlement dwellers in fire risk reduction

In this context, it is important to engage communities thoughtfully. Key pointers for working with settlement dwellers include[13]:

- **Being careful when identifying and engaging community members.** Identifying the right mix of community stakeholders is critically important. It is essential to include formally elected community leaders and other influential residents, both because they are important stakeholders in what happens in their communities and because they have the power to both facilitate and disrupt community-based initiatives. However, they may have their own agendas and might have a limited understanding of the needs of the most marginal and vulnerable households or groups. Their (and other dominant residents') opinions can drown out those who are less vocal or well-organised. Managing this complexity requires carefully balancing the involvement of different interest groups, and ensuring that both influential individuals as well as marginal groups are actively involved.

- **Anticipating social tension and the possibility of conflict**. Real participation and change can increase the likelihood of confrontation and conflict, between the powerful and less powerful and between different groups. For example, there may be tensions between more established residents and newer arrivals, especially if there are differences in language, culture and experience. Raising unrealistic expectations can also create problems, especially if interventions fail to live up to perceived promises.

- **Being a supportive facilitator – not an 'expert'.** Effective community engagement requires a shift from teaching to learning. People have a very good understanding of the issues they face and ideas for how to address them. Instead of imparting 'expert' knowledge, it is important to recognise this experience, and adopt a participatory approach that works with residents to identify challenges and solutions.

- **Involving external role-players.** Informal settlements do not exist in a vacuum; risk needs to be addressed holistically, and interventions should draw in external role players such as government departments and nongovernmental organisations, building relationships between

> ***What do we mean by 'participation'?***
>
> *Community or popular participation can be broadly understood as the involvement of people in making decisions about the design and implementation of processes, programmes and projects which affect them.*[86]

these stakeholders and target communities. Done effectively, this is essential to ensuring the sustainability of risk reduction activities.

2.8 Who needs to be involved?

Many different role-players should to be involved in any kind of community engagement processes. The following discussion is based upon the work by Holloway & Roomaney[13] on how to approach community-based risk assessment. It is useful to think of these stakeholders as fingers on a hand, as shown in Figure 2-6 – they are linked, and all are essential if the hand is to function effectively. They include:

- Local residents
- Local leaders – these range from officially elected Ward Councillors, to more informally appointed grassroot leaders
- Government functionaries – from various sectors and spheres (especially the fire department when considering fire safety)
- Community-based organisations (CBOs), NGOs and faith-based organisations
- Any other organisations already working in a particular community.

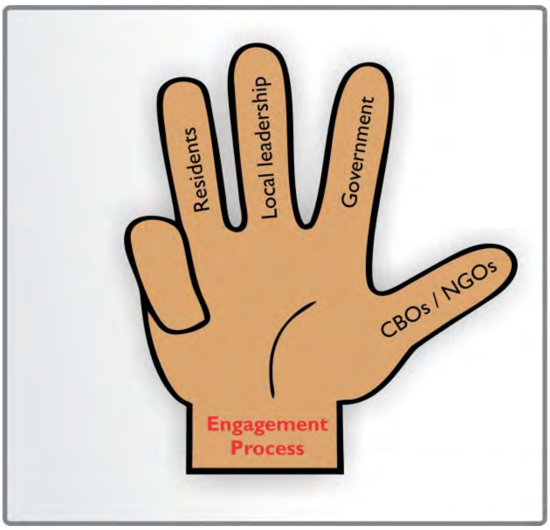

Figure 2-6: Players in the engagement process, as illustrated by a hand of inter-connected members

2.9 The collaborative process

There are several important steps in engaging communities about fire safety.

2.9.1 Scoping

Before engaging with any community, it is essential to undertake some basic background research, referred to as 'scoping'. The purpose of scoping is to scan existing information about an area, collecting information from various sources and in a range of formats. These can include newspaper reports, student theses, Integrated Development Plans (IDPs) and other official planning documents and reports, documents compiled by NGOs, or CBOs, but might include professional consultant reports should they be available. While census data can provide critical demographic information, other available datasets, such as fire incident records or even clinic records, can also be informative. Should such sources of information not be available, such as in relatively new areas, information can be compiled by interviewing local role players and even longer-term residents who may have a deeper understanding of a settlement's dynamics and its history. A participatory scoping approach employing community walkabouts, informal discussions and formalised community meetings is highly beneficial.

Spatial information is also important. General maps, for example, help to establish the location of a settlement within the broader area and reveal the nature of the surrounding geography - features such as rivers, wetlands, mountains, etc. Municipal maps, on the other hand, may provide more local detail, such as local roads and facilities, while aerial photographs and satellite imagery can reveal more detail about settlement density and existing services. Google Earth historical imagery can be used to establish how an area has changed physically over time, revealing characteristics of its development history.

2.9.2 Involving local leaders and gaining access

Participatory processes are notoriously slow, take time to set up and cannot be rushed. Outsiders to the community should always start by negotiating access well in advance and start building a relationship of trust with representatives from the community. This usually involves meeting with local leaders, particularly grassroot leaders who have an intimate knowledge of the community, elected Ward Councillors and even local religious leaders. Leaders will often need to consult other representatives from the community, such as local committee members, or even address a community gathering to ensure that a proposed fire safety intervention is acceptable to the general community.

Consultative dialogue with leaders can also ensure that the design of a fire-safety programme is appropriate for the unique local context. Enlisting their involvement in the design, planning and implementation of such a programme can also ensure their cooperation. Without community buy-in, interventions are frequently ignored or even undermined and will be short-lived. Including both leaders and general members of the community is thus critical in sustaining any planned activities and ensuring positive outcomes.

2.9.3 Adopting a holistic approach

Informal urban settlements today are complex, multidimensional and inherently fluid. The lives and livelihood strategies of the urban poor are increasingly contingent and precarious, daily faced with a range of hazards such as informal settlement fires. If such marginal areas are becoming 'hotspots' of urban risk,[24] change is perhaps the only constant for those inhabiting densely settled urban spaces that are continuously being reshaped and reconfigured as the number of residents continues to grow, both from natural internal population growth and the arrival of new settlers. In this risk-prone environment, any intervention should adopt a holistic approach, simultaneously addressing the social, physical and economic development needs of residents, built on participatory processes. As discussed above, it must be remembered that fire risk is often relatively low on people's agendas, with aspects such as security, health and food security taking priority.

2.9.4 Monitoring outcomes

It is important to sustain the relationships developed with community leaders and other project partners over the longer term, both for the continued monitoring and evaluation of an intervention and for enabling future collaborations. Tracking project outcomes is critical for recording the successes achieved and identifying the shortcomings. In this way, fire safety projects can be improved upon and adapted to changing conditions.

2.10 Summary

Informal settlements, and increasingly informal dwellings in low-cost housing areas, are complex environments. Engaging communities in fire-risk reduction requires a collaborative approach that brings multiple stakeholders together in a respectful way and helps participants 'buy-in' to the process and take ownership of it. This is time-consuming and challenging, and it is important to identify and navigate community dynamics to ensure that all voices are represented. It is also important to bear in mind that communities may have other priorities, and may not be as receptive to fire safety interventions. The process should also be ongoing, rather than once-off, to maintain relationships, monitor the success of interventions and accommodate changing needs and realities. Mutual learning and commitment are critical to success.


Image used permission of Justin Sullivan

3. Understanding fire safety engineering

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After considering the reality of informal settlements in the previous chapter, but before trying to develop fire safety solutions, it is important to understand both fire behaviour (the physics of why things burn) and fire safety engineering (design approaches to improve fire safety). This chapter covers these topics and applies them to informal settlement dwellings. Often fire safety interventions are ineffective because fire behaviour is not well-understood, so it is important to understand how a fire develops.

3.1 An introduction to concepts in fire behaviour

As a process, fire is the visible effect of a chemical reaction, known as combustion, when a combustible reacts with oxygen in the air, releasing energy in the form of light and heat. In order for this chemical reaction to take place the following three components are essential:[25]

- Fuel – the combustible material (i.e. couches, timber, cardboard, cloths, curtains, etc.);
- Oxygen – It is typically assumed that air is made up of 21% of oxygen; and
- Heat – A heat source is responsible for the initial ignition of the fuel.

These components are known as the combustion triangle. Often, a fourth component is added to the combustion triangle, namely the fact that chemical reactions must be allowed to take place. Figure 3-1 visually depicts the combustion triangle (or fire tetrahedron).

A fire is only stopped by removing one of the components of the fire triangle/tetrahedron. For example, covering a small fire with a fire blanket removes the oxygen component from the combustion triangle, and thus extinguishes the fire. Heat is required to convert solids and liquids into gases before flaming combustion can occur, as only gases burn. Hence, if heat is no longer applied to the fuel the fire will go out. This is the reason a glowing coal goes out when taken out a fire. Conversely, as fuel gets hotter, due to other burning items around it, it will burn faster.

Chapter citation: Cicione, A., Walls, R. and Antonellis, D. (2020), "Chapter 3: Understanding fire safety engineering", in Walls, R. (Ed.), *Fire Safety Engineering Guideline for Informal Settlements: Towards Practical Solutions for a Complex Problem in South Africa*, FireSUN Publications, Stellenbosch, pp. 23–52.

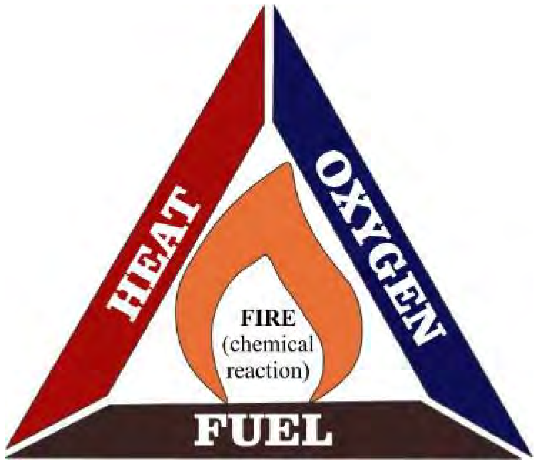

Figure 3-1: Combustion triangle/tetrahedron [26]

After the ignition of a fuel, the accompanied combustion process can be either (i) smouldering combustion or (ii) flaming combustion. Smouldering combustion is a flameless, slow-burning form of combustion, that can produce much smoke, but very limited heat. Smouldering fires occur when the fuel is not in the same phase as the oxidizer (i.e. air), hence the oxygen directly attacks the surface of a combustible. Flaming combustion, on the other hand, occurs in the gas phase as opposed to the surface of solid. In informal settlements, both forms of combustion are extremely dangerous, but in different ways. Flaming combustion leads to rapid fire spread, whereas smouldering fires are extremely toxic, as a result of more carbon monoxide being produced, and can burn unnoticed if an occupant is sleeping or is intoxicated. Someone may die due to asphyxiation long before neighbours notice a smouldering fire.

3.1.1 Understanding fire behaviour / Enclosure fire dynamics

The development of a fire in an enclosure can typically be divided into five distinct stages of fire development, namely, ignition, growth stage, flashover, fully developed fire stage and a decay period, as depicted in Figure 3-2. Based on past full-scale informal settlement dwelling (ISD) experiments [27–30], it has been found that ISDs typically experience the same behaviour, but usually they end with structural collapse, rather than decay. Although the y-axis of the graph portrays the gas temperature within the enclosure, a similar shaped curve describes the heat release rate (HRR) in the dwelling. The HRR here refers to amount of energy, in the form of heat, released during the combustion of an object. A video explaining the topics discussed below can be viewed at the following link: https://youtu.be/-F7zzRLQvgo.

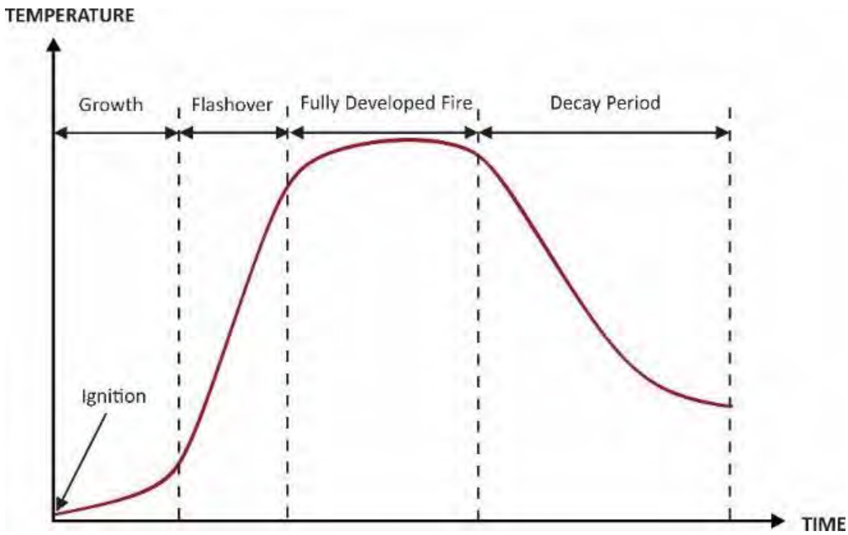

Figure 3-2: Stages of an enclosure fire's development

Ignition is the first sign of combustion and can either be piloted ignition (i.e. ignition by flame or spark) or auto-ignition (i.e. ignition without the presence of a spark or flame, but simply when something is heated up enough). The time-to-ignition of a material is typically governed by the ignition temperature of the material, the thermal properties of the material, and the heat flux the material is exposed to.

After ignition, the growth stage ensues. During the growth stage, the fire within the enclosure is still fuel-controlled, implying that there is still sufficient oxygen within the enclosure for complete combustion to occur. At this stage, the burning fuel releases combustion products in a gaseous form (i.e. such as smoke). Not all of these combustion gases react with oxygen, and since they are heated, compared to their surroundings, they rise with the fire plume to the top of the enclosure.[31] As more combustion gases accumulate at the top of the enclosure, it starts to form a hot layer. At this stage, the compartment can be approximately divided into two distinct layers, namely a cold layer and a hot layer as depicted in Figure 3-3.

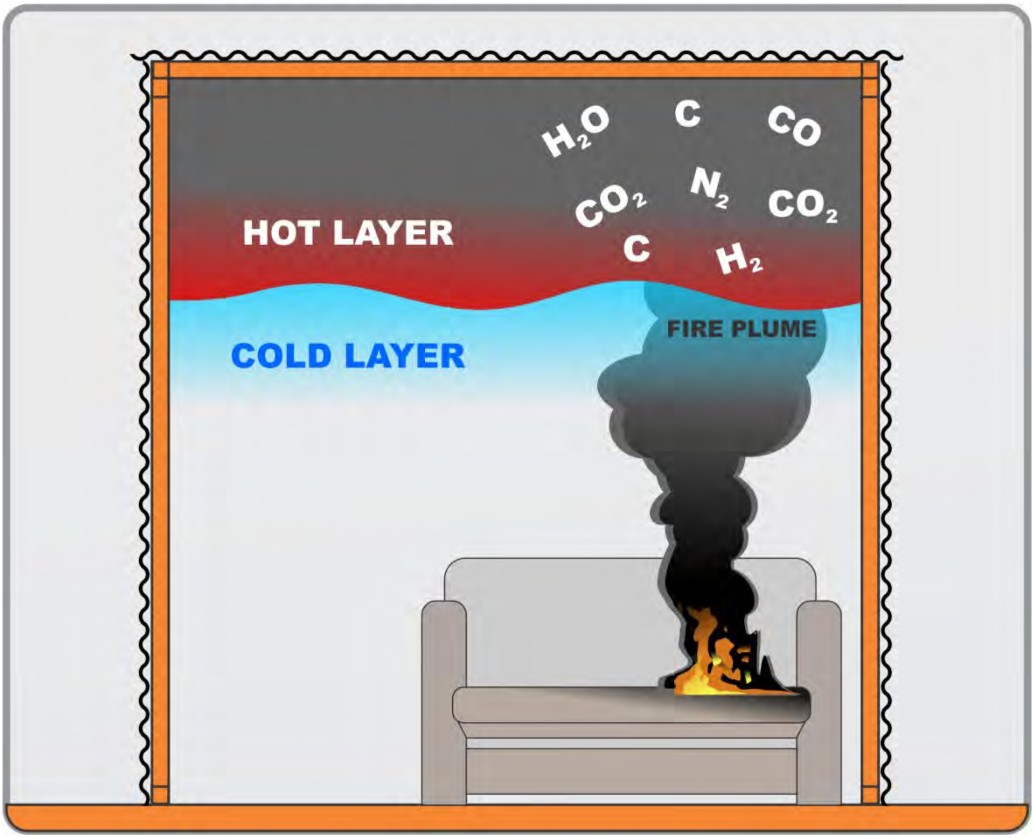

Figure 3-3: Hot layer and fire plume [26]

The hot layer emits radiation onto all the items in the dwelling and progressively grows as the fire burns. At a certain point, the radiation from the hot layer is sufficient to ignite all the combustibles in the dwelling. This is known as flashover, where a fire occurring in one part of a room suddenly spreads to the entire room in a very short period of time. During real fires, flashover is typically identified as the point where flames start to emerge from the dwelling openings, as depicted in Figure 3-4. Even a firefighter in full protective equipment will not typically survive a post-flashover fire if caught inside. The challenge with ISDs is that they are very small, with lots of materials that burn quickly, *and hence flashover can occur in as a little as one minute after ignition* (although this time varies significantly). This gives residents very little time to escape.

Figure 3-4: First signs of flashover during a full-scale ISD experiment

The enclosure rapidly enters the full developed fire stage after flashover, at which point the fire becomes ventilation-controlled, meaning the amount of ventilation (from windows, doors and openings) is not enough to provide sufficient oxygen for complete combustion to occur. Thus, as the unburned gases leave the dwelling and come into contact with oxygen they ignite and flames are seen emerging from the dwelling. During the fully developed fire stage, the HRR and gas temperatures are typically at their highest. Minutes after the fully developed fire stage is reached, ISDs often undergo structural collapse as a result of the construction methods and materials used to build these structures.[30] If a structural collapse does not occur, the fuel starts to deplete, causing the fire to change from a ventilation-controlled fire to fuel-controlled fire, which leads to a decrease in HRR and gas temperatures. This is referred to as the decay phase.

3.1.2 Fire spread between dwellings

Now that basic fire behaviour can be understood, we need to understand how a fire spreads over a surface, or from one dwelling to another, and for this, we must understand heat transfer. There are three forms of heat transfer, namely, radiation, convection and conduction.[32] Fire spread is influenced by many factors such as: topography (fire spreads faster uphill), wind (strong gusts can propel flames), moisture content, fuel (the type, geometry and positioning influence ignition and flame spread), and ambient conditions.

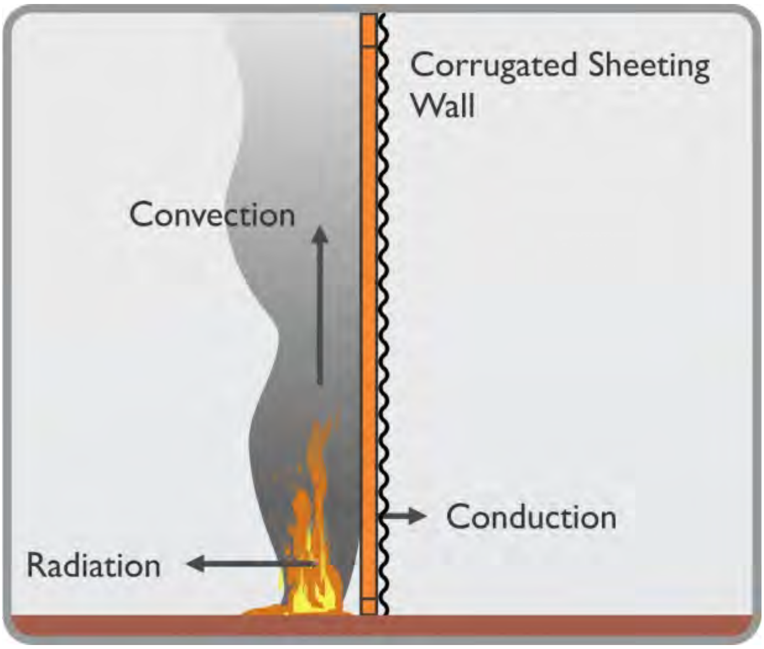

Figure 3-5: Modes of heat transfer [26]

Radiation is the transfer of energy by means of electromagnetic waves, and it has been identified as one of the main heat transfer mechanisms for informal settlement fires.[26,28] Conduction is the heat transfer mechanism, where heat is transferred through a solid material. Convection is heat transfer by the flow of fluids (liquids or gases). To understand this, considering the following: if you stand in front of a big fire (braai) and your eyebrows are burning, if you hold up your hand you typically find your eyebrows are then safe, even though the air in contact with your face remains the same temperature. This is because your hand has shielded your eyes from electromagnetic radiation, but not convective gases.

In recent years, a large amount of work has focused on analysing fire spread between ISDs through experiments and equations, or by means of computer models. It is normally safe to assume that fire spread does not occur between separated dwellings pre-flashover, and that is because the temperatures in the enclosure are relatively low and there are no flames emerging from the dwelling. Thus, for fire spread analyses or simulations, only the post-flashover behaviour is of interest (except where fire spread occurs due to materials stored between dwellings such as wood, rubbish, plastic items and similar products). When multiple dwellings occur under a single roof fires can quickly spread around internal dividing walls.

- ***Radiation and Separation distances***

It is often asked: how far apart do informal dwellings need to be to avoid fire spread? For a dwelling not to ignite it needs to be exposed to a low enough radiation that it will not ignite, or take a very long time to ignite (i.e. longer than the fire lasts). (The time-to-ignition of a material is directly proportional to material properties divided by the incident heat flux (i.e. radiation) minus the critical heat flux of the material.) The radiation emitted from a surface (i.e. the fire or a hot wall) to a point on a receiving surface (i.e. the home about to catch fire) is given by:

$$\dot{q}_r'' = \sigma \emptyset \varepsilon T^4 \qquad (3.1)$$

where σ is the Stefan-Boltzmann constant ($5.67 \times 10^{-8}\ Wm^{-2}K^{-4}$), and $\emptyset$ is the configuration factor (also known as a view factor) which is the fraction of energy leaving the surface of the emitter (burning dwelling in this case) that is received by the receiver (target dwelling in this case), ε is the emissivity of the emitter and *T* is the temperature of the emitter (in degrees Kelvin).

You do not need to be able to apply the equation discussed above, but there are two useful concepts to understand: (a) the influence of temperature (T^4), and (b) the configuration factor, $\emptyset$. As the temperature, *T*, increases the amount of heat emitted increases to the power of 4. Hence, when the temperature (in degrees Kelvin) doubles (e.g. going from 327°C to 927°C), there is 16 times the amount of heat emitted. The configuration factor accounts for the shape of the emitter and the distance and angle between the emitter and the receiver. As an illustration, a big door full of flames may cause an object 3m away to catch fire, whilst a small window with the same temperature flames may only cause an object to catch fire at 1.5m away.

Figure 3-6 shows the time-to-ignition of both timber and cardboard on the side of a target dwelling when heated by radiation from flames and hot metal cladding of either a single or double storey dwelling that is on fire. When the time-to-ignition tends to infinity (i.e. the vertical dashed line) a suitable separation distance is found. From this plot it can be seen that the required separation distance ranges between 2.8 m and 4.1 m depending on what is on fire, and what is being ignited. Furthermore, if strong winds were blowing it would decrease the time-to-ignition and increase the separation distance required.

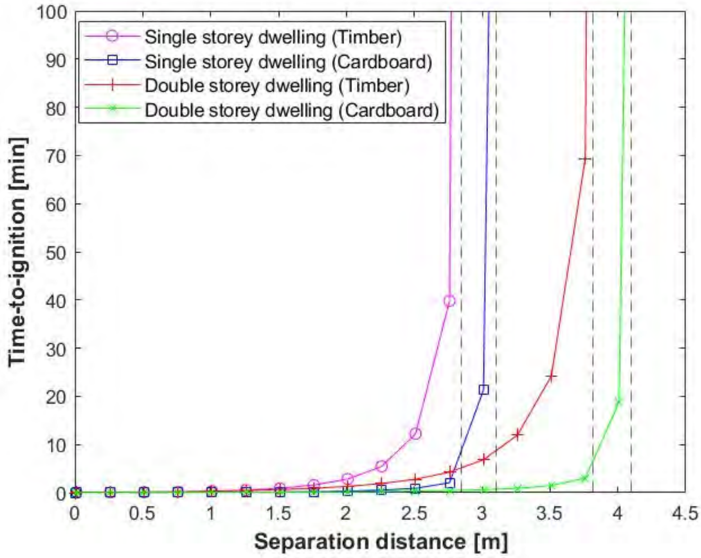

Figure 3-6: Time-to-ignition versus dwelling separation distance for a home (the target) exposed to fire from either a single or double storey dwelling with either timber of cardboard being the material that ignites on the target home.

- ***Flame impingement***

As introduced above, in addition to radiation another fire spread mechanism is flame impingement. Flame impingement is where flames come into contact with combustible items. Flames emerging from a door may be to 2-3 m long (or longer if multiple dwellings are burning), but constantly fluctuate and pulse from the fire. When these flames reach a non-combustible wall they may be stopped and not cause ignition. However, if there are small holes in walls then flame impingement through such openings can ignite cladding materials inside. This is one of the reasons that in Chapter 6 this work cautions against the use of fire resistant products (e.g. intumescent paints) on the sides of dwellings, because if homes are poorly constructed flames can easily penetrate dwellings, and the effect of the product may be nullified.

- ***Ember attack / Spotting / Branding***

In wildland (veld) fires most homes near to vegetation ignite due to the phenomena called ember attack, spotting or branding. In the 2017 Knysna fire disaster, it appears that spotting/ember attack played a significant role in the destruction of almost 1000 formal homes.[33] Spotting occurs when small, flaming particles are carried by wind, and can cause spot fires well ahead of the fire front (the front line of where the fire is burning), and sometimes they can even be transported many kilometres, as shown in Figure 3-7. In informal settlements it is highly likely that spotting occurs, meaning that windy conditions may cause fires to jump obstacles such as rivers, fire breaks, formal homes, or similar barriers. Unfortunately, very little data is currently available regarding spotting. When considering fire safety interventions it should be understood that fires may cross physical barriers setup to stop fire spread. Factors such as: (a) the amount of brand forming materials that is burning (trees with leaves, potentially some plastics, thatch etc.), (b) the speed and direction of the wind, and (c) the items brands land on (especially dry, easily combustible items such as leaves, plastics, cardboard, paper, etc.) will influence the extent to which spotting occurs. In relation to (c), ISD roof materials and gaps in construction, such as between the roof and exterior walls can make structures particularly vulnerable to ignition via firebrand or ember attack.[34]

- ***Summary of how dwellings catch fire***

The discussions above are summarised in Figure 3-7, showing the various ways that homes can be ignited.

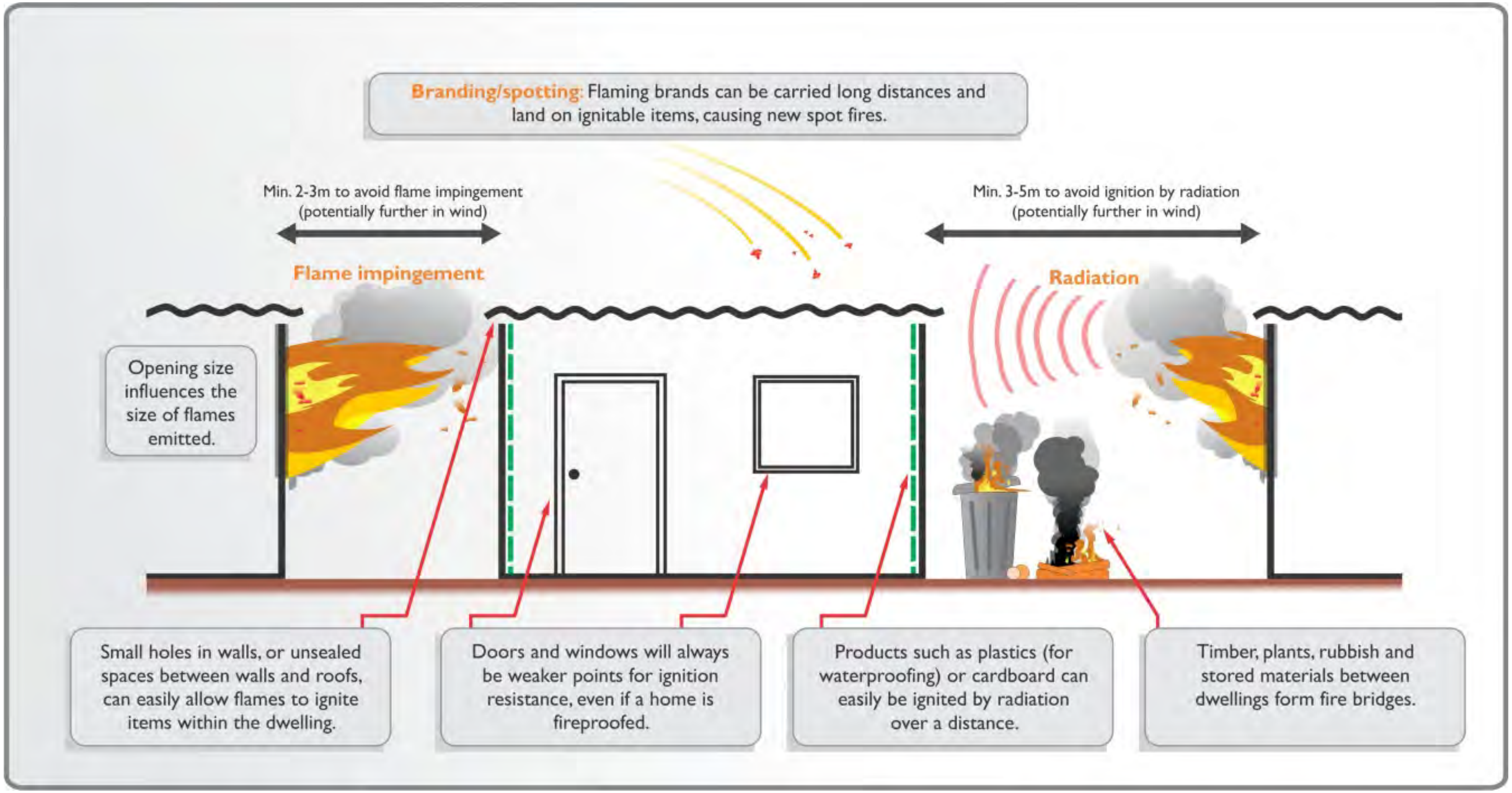

Figure 3-7: Illustration of how dwellings catch fire from flame impingement (left), radiation (right) and ember attack (top)

3.1.3 Behaviour of construction materials in fire and collapse

ISDs are often poorly constructed due to lack of access to materials and tools. Previous research[30] has shown that ISDs typically collapse within minutes after a fully developed fire stage is reached. Collapse may result in embers being thrown into the air or flames to be propelled from the dwelling, thereby enhancing spread, but may also result in roof sheeting smothering a fire. ISDs are typically constructed from material available in the immediate surroundings of the inhabitants and have high porosity (i.e. lots of openings for flames to penetrate) and are highly flammable (timber cladding, cardboard lining, plastics, etc.). However, there are also IS businesses where both new and used materials, panels and sometimes even entire pre-made dwellings are bought and sold.

The cladding material can significantly affect the radiation emitted from a dwelling and also the time-to-ignition. Other research projects[27] have investigated the effects of cladding material (i.e. timber planks versus corrugated steel cladding) and found that timber clad dwelling are significantly more vulnerable to fire spread. For steel clad dwellings, the internal lining material used (i.e. what people put on their walls) is of great importance and can significantly increase, or reduce, time to flashover and time-to-ignition. For example, using cardboard lining compared to gypsum boards as a lining material will significantly increase the chances of a dwelling igniting, and once ignited the cardboard would rapidly cause the fire to spread across the surface of the cladding, releasing a substantial amount of heat, which is enough to ignite all combustibles within the dwelling. The gypsum lining might not prevent fire spread, but would increase the time-to-ignition and would substantially increase the time to flashover. *Hence, an important lesson is: highly combustible wall linings make dwellings much more susceptible to fire.*

When considering interventions to prevent fire spread a very important issue is: <u>a *system* must be fire-rated</u>, and not only a product. The following are examples of *systems* that do not provide fire resistance: an excellent passive protection board with big openings at joints, a fire resistant spray-on product with cardboard stuffed into gaps between walls and roofs, or a fire resistant window which falls out when heated due to poor construction. Hence, always consider that when designing for the fire spread mechanisms discussed above a system in its entirety must be considered, and the system will only be as strong as its weakest link (which may be the door or window that were left open).

3.2 Considering performance safety levels and risk reduction in relation to fire codes

In most parts of the world, fire risk is regulated through a series of codes and standards. These may be highly prescriptive, or performance-based (i.e. they allow for certain performance criteria to be achieved, rather than only requiring specific rules to be followed), or somewhere along this spectrum of prescriptive versus performance-based. Regulations themselves may also fall along this spectrum. The National Building

Regulations (NBR) Act of South Africa (Act 103 of 1977)[35] is relatively performance-based for fire safety, with functional requirements provided by SANS 10400-T[36] which state:

Any building shall be so designed, constructed and equipped that in case of fire:

(a) the protection of occupants or users, including persons with disabilities, therein is ensured and that provision is made for the safe evacuation of such occupants or users;

(b) the spread and intensity of such fire within such building and the spread of fire to any other building will be minimized;

(c) sufficient stability will be retained to ensure that such building will not endanger any other building: Provided that in the case of any multi-storey building no major failure of the structural system shall occur;

(d) the generation and spread of smoke will be minimized or controlled to the greatest extent reasonably practicable; and

(e) adequate means of access, and equipment for detecting, fighting, controlling and extinguishing such fire, is provided.

The language, 'safe', 'minimized', 'sufficient', 'adequate', and 'greatest extent reasonably practicable' begs the question, what is good enough?

This is not an easy question to answer and so, like most other countries, South Africa's functional requirements are complemented by a set of prescriptive codes and standards which specify what is expected to achieve compliance. Within these requirements lies an implicit level of safety, or level of risk which is considered acceptable to society. This level of acceptable risk is not expressed in risk terms, i.e. acceptable losses based on wide range of accident scenarios together with their probabilities. Rather these requirements reflect an 'effect-based approach' which use reference scenarios for evaluating risk acceptability, largely based on historic events, numerous contextual factors, relevant scientific evidence and insights, approximation of society's safety expectations and willingness to pay for risk mitigation. These factors are considered by those involved with the incremental development processes of codes and standards (e.g. government, private industry, academia) – ultimately their collective judgement is codified.[37]

It therefore makes sense, that much of fire safety engineering is based on an effect-based approach. Performance-based analysis is often based on credible worst-case fire scenarios. By being conservative in the choice of reference scenarios, the analysis of probability is circumvented. There are exceptions of course, with probabilistic risk analysis, but this is not widely applied, at least not holistically to the entire system of fire safety, because it is time-consuming and the availability of relevant data can be limited.[38] Fire safety engineers often use deterministic analysis (i.e. a single answer from calculations) to evaluate designs that fall outside the scope of prescriptive requirements or to analyse fire scenarios that may pose higher levels of risk than those inherently assumed in the development of prescriptive requirements. Fire safety engineering is therefore a balancing act, and the definition of 'credible worst-case scenario' is a critical yet ever-changing concept as fire risk and society's expectations change.

If fire risk in informal settlements were to be analysed from the perspective of local regulations, the following questions must be asked:

(1) What inherent assumptions in codes and standards are not valid for informal settlements?

(2) What are the credible worst case scenarios for fire in informal settlements?

To make a point, let us assume a fire safety engineer is supporting the design of a single building within an informal settlement. If resources allow, they may elect to comply with prescriptive requirements from the relevant codes and standards. It would make logical sense that this would not only result with an improvement of safety compared to the surrounding informal buildings, but that this could result with a code compliant building. But depending on the regulatory context, i.e. where it falls on the prescriptive vs. performance-based spectrum, and the interpretation of requirements by the enforcement authority, this building may or may not be considered compliant. Either way, this approach would not produce a level of safety comparable to a building in a formal area because there are assumptions that codes and standards are based upon which are inherently not true in informal settlements, such as:

- Fire and rescue services will respond to a fire incident within a predetermined number of minutes.
- Firefighting water infrastructure will be available at the fire incident.
- Adjacent buildings are compliant with regulations, and therefore pose only a predetermined and acceptable level of risk to the building being evaluated.
- Separation distances to adjacent buildings are maintained throughout the life of the building (the built environment in ISs is continuously changing).
- When occupants escape a building to open air, they are in a place of relative safety.

Therefore it is proposed here that all prescriptive 'code compliant' buildings do not achieve the same level of safety because fire is a shared risk. Buildings in the middle of an informal settlement are exposed to the risks of the wider settlement. These risks cannot be fully mitigated unless extreme measures are taken to prevent fire spread to the building from adjacent buildings (e.g. robust fire resisting walls around the property), measures to ensure timely escape of occupants to an ultimate point of safety (e.g. dedicated and protected paths of travel), and adequate firefighting access and resources to prevent structural collapse (e.g. dedicated and maintained access road and water infrastructure). For most projects, this is not remotely achievable. Therefore, a narrow focus on code compliance would likely result with a lower level of safety than what is perceived. These issues, and others not mentioned, need to be addressed from a performance-based perspective to achieve the intended level of safety of regulations. Similar to other types of performance-based design, considering credible worst-case scenarios is therefore imperative.

However, processes to identify and evaluate credible worst-case scenarios for informal settlements have not been developed yet. This is a knowledge gap. Recent research in South Africa has provided insights on mechanisms of fire spread through fire testing, computer modelling, and observations of real fire incidents.[28,39] While this has enabled significant progress towards understanding fire spread, there are still complexities which have not been grappled with, such as human behavior and evacuation during a fire, or efficacy of firefighting efforts by communities and professional firefighters. Credible worst-case scenarios are characterised by physical and social processes which need to be understood holistically – fire, people, built environment, natural environment, etc.

Based on these current limitations, two fields of thought on how to improve fire safety in informal settlements emerge:

(1) Fill the knowledge gaps to a level where evidence and insights exist comparable to the formal built environment, to enable decisions to be benchmarked to existing regulatory requirements, and therefore implicit levels of safety deemed to be acceptable by society. This would take significant time and resources considering the high levels of heterogeneity and complexity within and between informal settlements. Almost inherently, the resources required to achieve this level of safety are out of reach for informal dwellers.

(2) Due to the inherent unregulated nature of informal settlements, accept that high levels of complexity and variability prevent a complete understanding of risk from being developed. Therefore, focus efforts on risk reduction, not achieving a specific safety level. This approach focuses on a balance between costs and benefits, and the identification of leverage points within complex systems. Approaches can be developed to better understand relevant sociotechnical systems and to gather evidence and insights to inform risk reduction investments and efforts.

3.3 What is fire safety engineering (FSE)?

Now that a basic understanding of the physics of fire has been provided, along with an understanding of fire safety performance, we need to use it to cautiously start looking at developing solutions using fire safety engineering approaches. The Institute of Fire Engineering (IFE) explains that:

Fire Engineering is the application of scientific and engineering principles, rules, codes, and expert judgement, based on an understanding of the phenomena and effects of fire and the reaction and behaviour of people to fire – to protect people, property, production and the environment from the destructive effects of fire.[40]

Hence, when it comes to improving fire safety in informal settlements there are various important aspects and objectives. The fundamental objectives of fire safety are typically to:

- Alert people regarding the presence of a fire,
- Provide a means of safe evacuation, considering those who may have mobility impairments or require assistance,
- Reduce the rate of fire spread,
- Limit the size of a fire,
- Protect buildings against collapse,
- Prevent fire spread to adjacent structures, infrastructure and other areas,
- Protect property,
- Provide access to support rescue and firefighting operations,
- Protect livelihoods, and to
- Protect the environment.

Considering the above, we need to ask some questions when trying to develop interventions and strategies for informal settlements, namely:

a) Are fire safety solutions based upon scientific and engineering principles or testing, following an understanding of how fires behave in informal settlements?

b) Also, do we understand how people behave in settlements – before, during and after events – such that we can provide solutions that are suitable and effective?

c) Finally, what is the objective of an intervention, is it for: (a) life safety, or the protection of (b) livelihoods, (c) property or (d) the environment? Typically a good fire safety intervention will address protect all four, but not necessarily.

Much work still needs to be done to improve our understanding of these issues, however, many improvements can be made by applying good fire engineering principles, and data from testing done on informal settlement dwellings (ISDs).

3.3.1 A design approach for fire safety in informal settlements

When approaching fire safety it is important to have a framework to ensure that a consistent and logical approach is taken. Often fire safety interventions implemented in informal settlements focus on only one aspect of fire safety (as introduced in Chapter 1), and forget the bigger picture, or do not address the main hazards a community is facing. When approaching the issue of fire safety the procedure used in this document will be based upon British Standard 7974[38], as it is commonly used in South Africa for fire safety. At its simplest level this fire safety analysis process consists of the items illustrated in Figure 3-8, as listed below:

1) Qualitative design review (describe what is desired)

2) Quantitative assessment (put numbers to what is desired)

3) Assessment against criteria (consider if what is proposed will give the desired result)

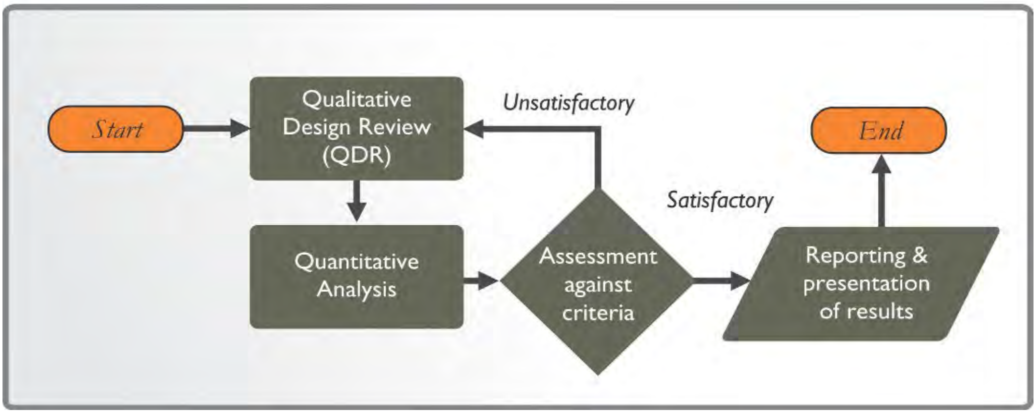

Figure 3-8: The basic fire engineering design and assessment process

The fire design process is often iterative in that many strategies or interventions may need to be considered until a suitable intervention or basket of interventions are obtained. Since there are many competing options, as explained in the rest of this document, a trade-off between competing objectives is typically required. Overall, the benefits of having a structured procedure is that it: allows for a disciplined approach, ensures that alternative solutions can be compared, gives a basis for why certain fire safety interventions may have been selected or not, permits innovation, and provides a documented approach that can assist future work. This process may sound complicated, but after going through the details provided in this work you should be able to be much more effective in evaluating solutions.

3.3.2 Qualitative design review process

The first step in the design approach is the Qualitative Design Review (QDR) process. Since the approach is *qualitative*, it means that it focuses on the quality of items, and is based on general descriptions of the problem or solution, without providing specific numbers. It is subjective, meaning that different people will have different inputs and opinions on what is produced.

Figure 3-9 provides a flowchart of the QDR process, giving detail on the sorts of issues that must be considered for each step. Through following the QDR process many challenges or issues can be identified, both regarding social and technical issues, that may not be found when simply selecting a single intervention (e.g. will a detector work for a smouldering fire? Can a fire easily cross the firewall you propose? If you built a firewall would people build homes up against it and then get trapped in a fire?).

1. Context analysis

- Review national, provincial and city policies relevant to informal settlement upgrading and service delivery.
- Develop an understanding of informal settlements and their relationship to the wider city (e.g. using a PESTLE analysis (Political, Economic, Sociocultural, Technological, Legal, and Environmental)).
- Identify key stakeholders that may support or oppose interventions, establish relationships with community and other key stakeholders, as appropriate.

2. Review settlement layout and inhabitant details

- Settlement location (Rural, urban, etc.), housing density, population density and demographics of communities.
- Community leadership structure in place
- Road access (especially for firefighting)
- Pedestrian access (especially for evacuation)
- Location of nearest fire department.
- Understand relationship between community and fire department.
- Presence of local infrastructure (fire hydrants, electrical supply, fire breaks, train lines, etc.)
- Understand both local vulnerabilities and capacity to assist work.

3. Establish fire safety objectives

- Is this focus: (a) life safety, (b) property protection and limiting the size of fires that occur, and/or (c) environmental protection?
- What resources are available to support fire safety interventions (project budget, sweat equity, household investment, etc.)? Can additional resources be accessed (additional project funding, donations, sponsorship, etc.)?
- Is it possible/feasible to expand or improve relevant infrastructure systems (fire hydrants, roads, electricity, etc.)? What support can the local government provide to improve access to basic services which could positively impact fire safety?

4. Identify fire hazards and the consequences of these hazards

- Consider national fire statistics regarding causes and which of these are present
- Can fires spread into the settlement from adjacent areas, such as wildland or industrial fires?
- Can fires spread from the settlements into adjacent areas, and what would be the result?
- Consider cascading effects (i.e. knock-on effects) affecting economic activities, natural and built-environment, etc.

5. Establish trial fire safety designs and interventions

- Based on a knowledge of the settlement, community feedback, available resources, and the fires that can occur, select interventions or strategies that may improve fire safety, considering constraints.

6. Identify acceptance criteria and methods of analysis

- What would be acceptable fire safety conditions in a settlement and how would you determine if they would occur?
- How far can risk be reduced to improve fire safety standards as much as reasonably possibly?

7. Establish trial fire and social scenarios

- Consider the dwelling of fire origin, and/or the dwelling fire spreads to.
- Type of fire and fire spread mechanism: consider smouldering, flaming, and/or wildland fires. Fire spread by flames and hot gases, radiation, or flaming brands.
- Cause of fire: electrical, arson, open flames, cooking, lightning, or heating.
- Fire size / stage: at ignition, growing fire, post-flashover (fully developed), a few homes on fire, or many homes on fire.
- Weather conditions: hot and dry, wet and cold (people indoors), wind speed, prevailing drought conditions, etc.
- Location of fire: At the periphery, in the middle, or in the densest area.
- Accessibility: Accessible area, inaccessible area (due to lack of roads, vehicles in roads, evacuating residents blocking roads, community preventing access, etc.).
- Responder to fire: community, fire brigade, non-governmental organization, other.
- Presence of inhabitants: few around (when at work), present and awake (morning or evening), present and asleep (night).
- Post-fire response: number of inhabitants affected, and availability of resources to support inhabitants.

Figure 3-9: Qualitative design review process for informal settlement fire safety. This describes the many factors that can be considered when selecting interventions for improving fire safety.

1. Context analysis

Context analysis requires widening our lens to understand the systems in place that produce risk and shape safety. Local context includes political, economic, sociocultural, technological, legal and environmental factors (referred to as 'PESTLE') that directly or indirectly influence fire risk. Approaches to improving IS fire safety are influenced by national, provincial and municipal policies, and the relationship of an IS and its residents to the rest of the town/city. These factors must be appreciated before undertaking any significant projects. It is very important to identify key stakeholders who may support, or oppose, any work being done, and to try and understand power dynamics between key stakeholders which can influence outcomes. It is imperative that relationships with community members and stakeholders be established early on. Context analysis requires engagement with diverse stakeholders to bring all relevant perspectives to the table. Ultimately, fire strategies should be reflective of the needs, desires, and experiences of the community.

2. Review the settlement layout and details of the area

Before looking at how to improve fire safety many aspects need to be understood, as outlined in Figure 3-9. As explained in Chapter 2, it is important to understand how the community functions, the leadership structures in place, demographics, general layout, and access to the area (both when roads are relatively clear, and during busier times, such as during a big soccer match when cars are parked outside certain buildings making access difficult).

3. Establish fire safety objectives

Ultimately the aim of fire safety is first-and-foremost preserving life, with property protection being a secondary issue. Life safety fire standards, such as NFPA 101[41], state that the goal is to (1) provide an environment for occupants that is reasonably safe for all those not intimate with the initial fire development, and (2) improve the chance of survival of those intimate to the initial fire development. However, for IS fires it must be understood that in some instances indirect impacts on livelihoods and life safety may be greater than direct impacts, and the protection of homes is important for long-term sustainable development. Immediate needs of fire survivors, such as food, shelter, and water need to be met to maintain life safety. Longer term, negative impacts to livelihoods and development are likely if, for example, people are injured or killed in the fire (e.g. parent unable to work), businesses are disrupted, community facilities are destroyed limiting access to childcare or education, or people need to take out loans to rebuild homes (increasing indebtedness). Recovery after a fire is a dynamic process where aims to build back better are often not achievable given limited sources and reconstruction may result with poorer quality homes, especially where materials are re-used post-fire, and there is less access to basic services such as water, sanitation and energy infrastructure.

This means communities are often more susceptible to fire and other shocks and stresses after they have experienced a fire, perpetuating a vicious cycle of hazard exposure and vulnerability. Protection of livelihoods is considered as a possible fire safety objective, as well as protection of life, property and the environment. Therefore, political and socioeconomic interventions should be considered alongside more traditional fire risk reduction measures in the development of an Integrated Fire Safety Solution or Strategy.

Due to the rapid development of fires within informal settlement dwellings it is very difficult to protect people intimate to the fire once a candle or paraffin stove has been knocked over and there may be less than one minute to escape (as discussed in Section 3.1). Hence, a sober and realistic assessment needs to be made of the objectives that are trying to be achieved, acknowledging that perfect fire safety is not possible. Even in formal houses fire fatalities can occur, and this is severely exacerbated by the presence of dense, highly flammable homes in informal settlements.

The objectives being set for fire safety interventions and strategies are highly influenced by:

- What resources are available to support fire safety interventions (project budget, sweat equity, household investment, etc.)? Can additional resources be accessed (additional project funding, donations, sponsorship, etc.)?

- Is it possible/feasible to expand or improve relevant infrastructure systems (fire hydrants, roads, electricity, etc.)? What support can the local government provide to improve access to basic services which could positively impact fire safety?

When considering which interventions are being implemented it should be assessed what interventions will provide the greatest benefit relative to the resources available. Municipal infrastructure plays an important role in the provision of water, road access for response teams, pedestrian routes for escape, power supply facilities to reduce the risk of fire (but also need to be shutoff during firefighting operations), and the location of fire stations. Unfortunately, the nature of informal settlements means that they typically are built in areas not serviced by bulk infrastructure, and have limited facilities. If funding is available for infrastructure upgrades this can have significant fire safety benefits.

4. Identify hazards and the consequences of these hazards

Based on reports from the fire services the cause of fires in informal settlements in South Africa in 2018 is shown in Figure 3-10, which is a breakdown of the 5591 reported IS fires in that year.[4] This data is compiled annually by the Fire Protection Association of SA (FPASA), but, as discussed in Chapter 1, the real number of fires will be higher due to many incidents not being reported and if data submitted by brigades is not complete.

An important aspect to note is that "Undetermined" and "Other" causes make up almost 50% of the data. This lack of specificity occurs as it is often very difficult to accurately determine the cause of a fire when everything has been destroyed in a home. Investigators and firefighters regularly have to rely on witness accounts of what happened, but individuals who caused a fire, even if accidental, may not give an accurate account if they fear reprisal from neighbours who have lost their homes, and in some instances witnesses may not come forward with information. Hence, such statistics should be interpreted accordingly.

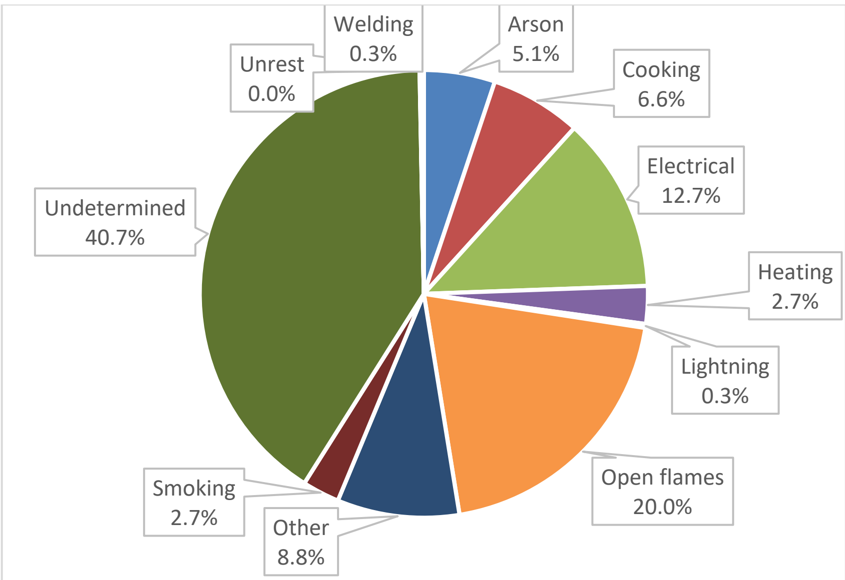

Figure 3-10: Cause of informal settlement fire in South Africa in 2018 (data based on [4])

Excluding "Undetermined" and "Other" causes, of the identified causes: open flames make up around 40% of the remaining incidents, electrical issues account for 25%, cooking accounts for 13%, arson at 10%, and heating is at 5% of the fires. Since it is not possible to determine whether cooking or heating incidents involved open flames, the number of incidents involving open flames may be significantly higher than 40%.

The data above gives a basis for determining what hazards are likely to affect a settlement. Data relative to a specific settlement, or area, may be available from local fire brigades that can provide more accurate details. It must also be considered what hazards are present nearby that could influence fire safety, such as open wildland areas that can burn, industrial facilities, electrical pylons, etc. Within the settlement being addressed each hazard should be investigated. Questions that can be asked include: are people using paraffin stoves, coal stoves (especially near coal regions), candles or a variety of items? When electricity is available, are there formal metered connections in place, or are there a large number of informal electrical supplies (see Section 2.6), with wires dangerously running between dwellings? Are plugs being overloaded in individual homes, and are local substations or transformers regularly be affected? These aspects will be discussed in greater depth in Chapter 6.

5. Establish trial fire safety designs and interventions

As introduced in Chapter 1, holistic fire safety involves addressing: (a) active fire protection (e.g. fire brigades), (b) passive fire protection (e.g. better construction materials), and (c) fire prevention/risk of ignition. Based on which aspect can be most effectively addressed (but considering the available resources) one or more potential interventions or fire safety strategies should be identified. The practicality and technical details of the interventions now need to be tested. Chapter 6 discusses various interventions that can be considered.

6. Determine acceptance criteria and a way of analysing solutions implemented

At this stage, broad concepts of fire safety must be converted into more specific criteria that can be addressed. For the application of fire safety engineering to formal areas, it can be much easier to identify these acceptance criteria, for example: the *objective* of ensuring occupants are able to leave in reasonable safety is addressed by a *design target* of maintaining tenable conditions (i.e. still relatively safe) in escape routes until all occupants have evacuated, which is described in specific *performance criteria* terms by ensuring that smoke layers remain at least 2.5m above the floor and remains below 200°C until evacuation is complete. Such specific technical details are not possible for ISs due to the complexities of the physical indoor/outdoor environment, leading to complex fire behaviour, and a lack of predictability of human behaviour and evacuation during a fire. However, based on the fire scenarios potential goals may be:

- Fires do not spread beyond a certain number of homes in low to medium wind conditions (e.g. 5-10 homes).
- Fire does not spread between buildings where a determined minimum separation distance (e.g. 2.5m) is maintained.
- Detectors will notify inhabitants of either smouldering or flaming fires and have a limited number of false alarms.
- Suppression systems supplied to inhabitants do not get removed/stolen/sold within a certain number of years of being issued, and can suppress either a small or medium fire.

- Fire brigades can access a certain percentage of the settlement (e.g. 70-100%).
- The fire brigade phone number is generally known by inhabitants (e.g. 70% of school children and 50% of adults).
- Relationships between the community and fire brigade are improved such that community members will assist fire trucks in accessing fires. This can be quantified by determining the number of incidents where residents assist firefighters or quantified by the number of attacks on firefighters.
- Local municipal departments and other organisations are capable of responding to the housing needs of a certain number of people who have lost homes in a fire.
- Community members have access to insurance so they can meet their basic needs, rebuild and replace property in the fire.

7. *Establish trial fire scenarios*

Figure 3-9 highlights the factors that should be considered when describing fire scenarios:

- Dwelling considered: dwelling of fire origin, or dwelling the fire spreads to
- Type of fire and fire spread mechanism
- Cause of fire
- Fire size / stage
- Weather conditions
- Location of fire
- Accessibility
- Responder to fire
- Presence and actions of inhabitants
- Firefighting resources for community and fire brigade
- Post-fire response and recovery

The following list provides more specific considerations for fire scenario development:

1) First consider the ignition source scenarios in the dwelling of origin:

a) Smouldering fire
b) Open flame fire
c) Electrical fire
d) Oil fire
e) Fire spreading from wildland area
f) Arson, etc.

Depending on how the fire started the intervention required may be different. For example: a candle that has been knocked over can be put out with water, but an oil fire on a stove should be put out with sand, fire extinguisher, thick wet material or a fire blanket.

2) *Consideration of the dwelling where the fire originates, once the fire has ignited. Typical examples of fire scenarios include:*

    a. A smouldering fire starts and produces large amounts of toxic smoke, but very limited amounts of heat. People are inside the home and sleeping. There is a fatal risk of asphyxiation.

    b. A flaming fire starts in a home where people are present, and they could either be awake or asleep.

    c. A flaming fire starts in a home where nobody is present. It develops until the entire home is on fire (post-flashover). The fire now starts to spread to adjacent homes.

For all these cases: how long will it take to detect the fire, who is able to suppress the fire, what equipment is available, etc.? See Chapter 4 regarding the fire timeline.

3) *Consideration of dwellings that a fire will spread to:*

    a. Fire spread mechanism scenarios (see Section 3.1.2 above):

        i. Flame attack/impingement

        ii. Thermal radiation

        iii. Flaming brands/ember attack/spotting

Flames and hot gases can be emitted at least 2-3m from burning dwelling openings, and even further from large fires. Any easily combustible item they encounter could be ignited. Radiation affects items at a distance, and relatively combustible items (plastics, material, foams) are likely to catch fire if within 3-5m of a fully developed fire. Small burning particles, called embers or flaming brands, can be carried long distances, depending on wind speed, and cause ignition (spot fires) ahead of a fire front (e.g. 10-50 m from the fire, although this varies widely). This can mean that physical barriers such as walls, ditches, fences or rivers can be crossed by fires, and may be less effective than expected.

b. Weather conditions:

  i. Low wind (e.g. "light breeze" on the Beaufort scale, with speeds of 6-11 km/h)

  ii. High wind (e.g. "strong breeze" or higher on the Beaufort scale, with speeds of 39-49 km/h or more)

  iii. Dry conditions / prevailing droughts

For limited or low wind conditions the aim should be to keep the fire contained in a relatively small area. In high wind conditions, it should be identified what area of the settlement the fire can be kept within (compartmentation), and how this can be done.

4) Fire response and suppression scenarios:

a. Location of fire and accessibility of dwellings relative to road access: (i) at the periphery, (ii) in the middle of a settlement, or (iii) in the densest part of the settlement.

b. Presence of inhabitants: (i) few inhabitants and generally awake (e.g. during the day), (ii) many inhabitants and generally awake (e.g. morning or evening), or (iii) many inhabitants and generally asleep (night)

c. Road accessibility: (i) roads generally clear, or (ii) roads relatively blocked and access is difficult

d. Responders who will attempt to suppress fires: (i) communities, (ii) fire department, and (iii) other organisations (non-governmental organisations, local landowners, other government agencies such as national parks, etc.)

3.3.3 Quantitative assessment

Where possible, it is useful to try to quantify how an intervention should function. Depending on the nature of the intervention or strategy employed various targets can be set, such as:

- Limiting the number of fire events that occur per year.
- Reducing the size of large fires to a certain number of dwellings, adjusted to suit prevailing weather conditions and the time taken to contact the local fire station.
- Proportion of the community that can evacuate during a fire (this should generally be as close to 100% as possible).

- Proportion of the community that receive the intervention being rolled out.
- Proportion of the community that receive training.
- Proportion of the community that know the correct local fire department number.
- Availability of local infrastructure (electrical or water supply).
- Having a certain minimum response time for the local fire station.
- Amount of resources available for after a fire to assist people who have lost homes or been injured.

3.3.4 Assessment against criteria

Based on the processes outlined above it would need to be determined whether the intervention(s) or strategies being proposed meet the criteria proposed. Unfortunately inherent high levels of fire risk in informal settlements and limited resources means that acceptance criteria will typically be below that which would be sought in the formal built environment. By going through this process with various interventions it could be determined whether the solutions proposed, or basket of solutions, are the most effective options possible. There will never be an easy and simple solution that solves the problem. However, risk reduction and fire safety improvements are possible, and improved living standards can be achieved for inhabitants.

3.3.5 Illustrating fire safety scenarios and approaches

Based on the fire scenarios provided above, worst credible scenarios should be identified and addressed. Consider the following two examples:

- *Example A*

A new settlement has emerged on the outskirts of a larger town, a reasonable distance from the nearest fire station, but serviced by that station. Several standpipes (water supply taps typically for domestic supply) are available throughout the settlement, but there are no operational fire hydrants. The settlement is relatively dense, although there are still many paths and access ways throughout. A local NGO is assisting with equipping the community to fight fires and has identified bucket brigades as a potential solution, amongst various others. They are considering providing 20 litre buckets to inhabitants.

Fire scenario 1: Smouldering fire in a single dwelling

Analysis: The buckets provided would not assist in any way with early warning, and sleeping or intoxicated people may perish in the fire. If the residents detect the fire (by smell or seeing the smoke) while it is still small and they escape, they could potentially put out the fire if water buckets are available nearby. A smouldering fire moves slower, so water could be obtained from a local standpipe, or from neighbours.

Fire scenario 2: Open flames causes ignition in home.

Analysis: Water buckets would typically be suitable for suppressing a flaming fire. If the fire was small then 1-2 buckets would be sufficient. It would be important to determine how close standpipes are, and what water flow rates can be obtained from them. If a dwelling fire becomes fully developed then a constant supply of buckets would be required. Since the settlement has many access pathways hopefully the fire could be contained between pathways. Once the fire has affected a number of dwellings the water supply, and distance to the nearest supply point, would influence whether the residents would be able to reduce fire spread rates. Community training on bucket brigade usage for such instances may assist. Some fires will not be contained, especially when the wind is strong and the area is very dry. As the fire station is further away it is critical that people phone the correct number early on, and the community members try contain the fire until the brigade arrives. *The fire brigade's number could be printed on the side of the bucket to assist with awareness.*

People may sell buckets or use them to store products, meaning those distributed by the NGO may not be available for firefighting at the time of a fire. Also, if low quality buckets are provided they may break through regular usage.

Fire scenario 3: Electrical fire due to overloaded plugs or bad wiring.

Analysis: Refer to Annex A for how to respond to an electrical fire. If community members placed water directly onto electrical connections it could potentially be dangerous. Hence, training would need to be carried out regarding turning off the electrical supply to the item where the fire started (if possible), and methods to smother the fire should potentially be used. Hence, training would need to accompany the buckets. In some instances, the application of water may put the fire out, but electrocution could occur.

Fire scenario 4: Oil fire starts on the stove

Analysis: Refer to Annex A regarding how to respond to an oil fire. Once again, water should not be applied to the fire, and the community would need to be made aware of this. The fire should be smothered, or sand placed upon it. Water thrown onto an oil fire can cause a "boil over" where the water suddenly turns into steam, causing the burning oil to be propelled out of the pot and all over the room.

- *Example B*

A fire brigade is investigating whether to purchase a small, mobile firefighting vehicle. The following might be fire scenarios that could be considered:

Fire scenario: A fire starts in the densest part of a large, relatively dense settlement at night. Most inhabitants are home, meaning that there are numerous additional vehicles around, limiting road access. Inhabitants are generally asleep. A relatively strong south-easterly wind is blowing. Limited water supply is available in the area.

Analysis: The mobile firefighting unit would be able to access the settlement more easily than larger fire trucks, and is likely to get through the local streets, as long as a single lane is available. Since residents are asleep it may mean that the time from ignition to detection will be longer, and so the fire may grow larger. The densest part of the settlement is about 50m from the nearest road, and it would need to be ensured that the mobile unit has enough hose lengths to reach that far. Accessing that location may cause additional delay, and since the settlement is dense the fire will spread relatively rapidly. Hence, overall the mobile unit may be useful for a quick initial attack to try to contain the fire, or suppress the fire if the fire brigade is phoned quickly. However, due to the settlement density, limited water infrastructure available, and limited water capacity on the mobile unit, additional firefighting vehicles would likely be needed. Especially if there were high winds, the fire brigade may need to dispatch other units at the same time as the quicker mobile unit, due to the chance of the fire becoming out of hand.

3.3.6 Reporting and presentation of results

Once a number of fire scenarios and interventions have been considered, the selection process should be documented. This will assist in evaluating the intervention/strategy with time. There should be a follow-up to ensure that the effectiveness is assessed, and, where possible, fire statistics for the area should be monitored. (Note that fire statistics can vary significantly year to year so an extended period of a number of years is required to assess most interventions). Also, other settlements or municipalities can learn from the exercise and determine whether the intervention would be suitable for them. Hence, it is important to document the factors that influenced the decision, as these may not be applicable to another area. For example, a municipality that could use a mobile firefighting unit for both informal and wildland fires may have significant justification to purchase the unit, whereas a municipality with no wildland fire problems may have different objectives.

When fires do occur the local fire department should investigate them to the extent of their capacity to identify what happened, the extent to which interventions did, or didn't, work and lessons that can be learnt. This is very important for assessing effectiveness and identifying both shortcoming and benefits of interventions.

3.4 Summary

From the discussions above some important lessons or concepts can be taken away with regards to fire safety in ISs. Some of these are:

1. If construction materials are exposed that can easily be ignited, a dwelling is much more likely to catch fire. Separation distances required between single storey homes with timber exposed are around 2.5-3.0 m (but much further when the wind blows), whilst if cardboard, plastics or other easily combustible items are exposed to larger fires then separation distances increase to about 5m.

2. Combustible interior cladding is very dangerous. The time an inhabitant has to escape from a dwelling, and the speed that a fire moves through a settlement, is influenced by the time it takes for a fire to develop from ignition to flashover. If a dwelling is lined with products that are easily ignitable, and they cause fast fire spread across them, they will release a lot of energy quickly meaning that flashover will occur in a matter of minutes. If a dwelling has no combustible cladding on the walls and floor it may not catch fire at all. When people are trying to save their homes during a fire they could try pull down combustible items, and close doors and windows, to reduce the chance of fire spread.

3. Flame impingement is important. Flames emerging from a burning home may be a number of meters long, and will penetrate holes in poorly built homes. A good place to start when fire proofing homes is to try close openings (especially between walls and roofs) with non-combustible material (and remove highly dangerous newspaper that has been shoved into openings to stop draughts).

A framework for developing fire safety engineering approaches is presented. From this, it would be ideal if organisations can identify a number of interventions or strategies to improve fire safety across the board. When considering strategies, a variety of scenarios should be considered as there will be no "one-size-fits-all" intervention. By going through a design review both the benefits and challenges associated with strategies can be identified.

Image used permission of Justin Sullivan

4. Informal settlement fire incident timeline

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When a fire breaks out, time is of the essence! Hence, this chapter focusses on understanding fire incidents and the different components of them. The longer it takes for the fire to be found, authorities to be notified, firefighters to be dispatched, firefighters to travel to the fire location, and time for setup and suppression, the larger the fire will become. A significant delay in *any part* of the process will result in more homes being burnt down. Hence, even if the response time of the local fire department is excellent, but it takes a long time for the message from the community to get through to them (as observed during the 2017 Imizamo Yethu fire[42]), the overall response time will be poor and more homes will be destroyed.

Figure 4-1 presents the timeline of a large fire incident, which will now be discussed, to understand how role players can assist in reducing the impact of a fire.

4.1 Ignition

Ignition is the point in time at which the fire starts, and this may be due to a spark, heating of a combustible object, an electrical fault or a cooking fire becoming out of control. Each fire will take a different amount of time to develop and spread, as discussed in Chapter 3. A smouldering cigarette on a foam mattress may require many minutes before the first flames are observed. However, if a full paraffin stove is knocked onto bed linen then full room involvement will happen within around 1-2 minutes.

Depending on what started the fire, where it is, and who is around, there may be a period of time before a person(s) notices the fire and can react to it. The time until a fire is observed is affected by factors such as: the age of the person (young children may not know how to react), whether the closest person is sleeping or under the influence of alcohol or drugs, the time of day (i.e. whether smoke or flames are detected easily), the presence of smoke/fire detectors alerting other inhabitants, and the nature of what is burning.

Chapter citation: Walls, R. and Smith, M. (2020), "4. Informal settlement fire incident timeline", in Walls, R. (Ed.), *Fire Safety Engineering Guideline for Informal Settlements: Towards Practical Solutions for a Complex Problem in South Africa*, FireSUN Publications, Stellenbosch, pp. 53-62

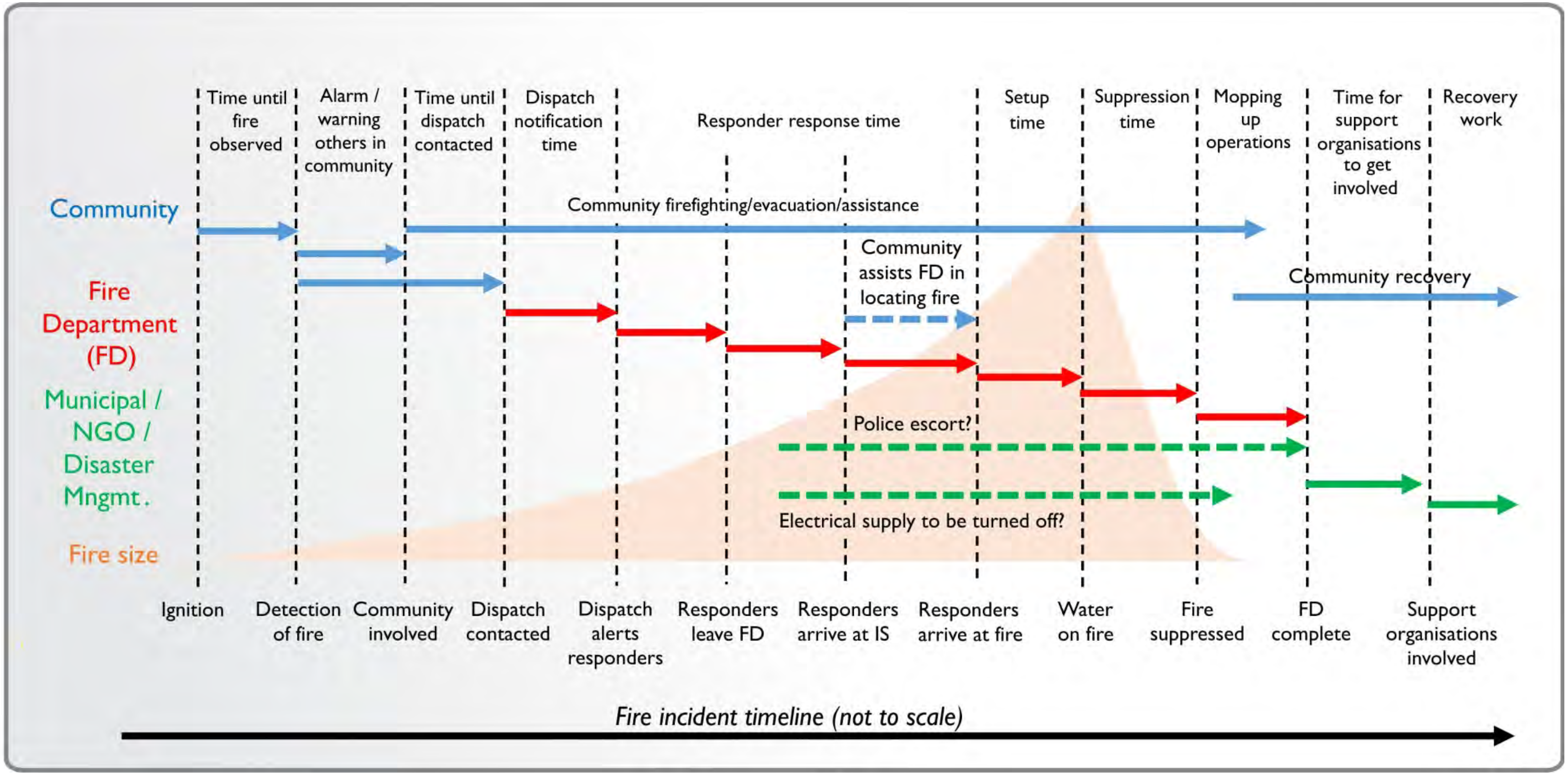

Figure 4-1: Timeline of a large fire incident illustrating the roles/activities of different groups and also how the size of the fire grows

Image used permission of Justin Sullivan

4.2 Detection of a fire

Once a fire has been detected the person(s) who finds it needs to decide how to respond. If the fire is small and can easily be suppressed the fire may immediately be put out. This is where it is beneficial if inhabitants are able to suppress small fires using water buckets, hosepipes, thick blankets or anything else. Figure 4-2 shows community members trying, unsuccessfully, to suppress a large fire using water buckets. If the people responding are unable to intervene, they should seek to notify other inhabitants and the authorities immediately. The more people that are notified early on, the better. For the remainder of the fire incident, discussed below, the community's involvement should not be overlooked as they play a pivotal role and can assist in many ways. Important specific evacuation and preparedness procedures that can be carried out by inhabitants are discussed in Section 6.2. In some parts of the world, and in more rural areas, community members may be the only respondents to fires.

Figure 4-2: Community members attempting to suppress a fire with water buckets thrown from a roof (Image used permission of Ryan Heydenrych, Vulcan Wildfire Management)

4.3 Community involved

It is important that other community members be notified as soon as possible such that they can undertake evacuation, firefighting and various assisting activities. Due to dwellings being close to each other, loud shouting is often enough to warn people within the vicinity of the fire regarding what is happening. However, in large settlements it may take a period of time before people further away, say 100-500m, become aware of the possible danger. If loud music is playing or if there are strong winds it may become more difficult to notify other residents. Hand cranked alarms have been used as a fire alarm in informal settlements in Kenya and there are ways to network alarm devices so that they notify community members of a fire in the vicinity of their home via SMS. Community communication groups (e.g. WhatsApp groups) could potentially be used to some degree.

4.4 Dispatch notified

Someone in a community needs to notify the local fire department such that they can respond. Issues regarding which number should be contacted are discussed in Section 6.3.2. Often communities contact the wrong number (e.g. 10111), or for many reasons may try to suppress the fire for a significant period of time first, before notifying the fire department. It is pivotal that the *correct* number be called *as soon as possible*. [Note that South Africa is in the process of adopting a unified emergency number that will replace all other numbers. When this centralised system is in place communities should be told to phone that single number for all emergencies.]

4.5 Dispatch alerts responders

The call centre receiving the emergency call needs to relay it to the station and responders who will be attending to the call. Ideally, this process should occur quickly, although may be delayed by a variety of factors. The responders then need to put on their gear and leave the fire department.

4.6 Responders leave fire department (FD)

The Fire Department (FD) responders now need to find the fastest way to the fire site location. Factors such as traffic, the quality of local roads, the distance to the fire, the familiarity of the drivers with local routes and the availability of technology to determine a suitable route will affect the time to respond. If FDs have pre-planned routes and know their way around local settlements, this will reduce response time.

4.7 Responders arrive at Informal Settlement (IS)

For most fire callouts in formal dwellings, a differentiation is not made between arriving at a suburb/area, and the arrival at the fire location within that suburb/area. However, for IS fires a differentiation is required. In dense settlements with very restricted access (e.g. narrow roads, no roads, cars parked in access ways, low hanging electrical cables, etc.) the responders can be delayed from reaching the fire site, even if they can reach the IS relatively quickly, as shown by the challenges observed in Figure 4-3. Also, depending on the amount of information provided by the person(s) contacting the dispatch it may be difficult to determine the exact location of the fire in a larger settlement. During the day a smoke plume may provide good guidance, but at night (when many of the fires occur) the smoke or flames may not be readily visible from the main roads. Street addresses are often not available which limits the use of GPS routing. In an ideal situation, community members could meet the FD at the edge of the settlement and guide them to the fire location, which would assist in reducing response time. Also, community members should seek to keep access roads clear.

As an alternative to GPS, what3words has been shown to be very effective tool to communicate the precise location of an emergency to emergency services. What3words has assigned a unique combination of three words to each 3 square metres of the entire world. Inhabitants could use the what3words app to identify the fire location or as a preparedness measure, keep the three words identifying their home location in an easily accessible location, such as on their exterior door, so it can be easily referenced in an emergency.[43]

Figure 4-3: Congested roads during the Imizamo Yethu fire of 2017 made access difficult to firefighters as people, possessions and vehicles blocked access ways (Image used permission of Bruce Sutherland, City of Cape Town)

4.8 Responders arrive at the fire

Once the responders arrive at the fire location various strategies can be employed to fight the fire. In most cases, water is supplied from fire trucks and tankers. If hydrants are available, operational and can be found (see Section 6.3.4 for discussions) these could be used. The further homes are from an access road the more lengths of hose that will have to be run, and the longer it will take to provide water to the fire. If communities are antagonistic towards the FD it may delay the process, and in some instances, the FD may not even be able to become involved. For many settlements, especially during periods of protests, a police escort may be required to assist and protect firefighters. Also, depending on the area it may be necessary to disconnect the electrical supply to the area, and the local municipality will need to assist in this regard.

For larger fires additional resources from other fire stations may be requested to assist.

4.9 Water on fire

Once the FD has setup they can start applying water onto the fire. They may also use alternative systems such as nozzle aspirated foam systems (NAFS) or compressed air foam systems (CAFS). The length of time it takes to suppress the fire is highly dependent on the fire size, the FD resources available, the amount of water available, settlement density, wind speed, terrain, community support/antagonism, and access. The suppression process may range from a matter of minutes to many hours. Figure 4-4 shows a firefighter applying water onto a large IS fire. From the intensity of the flames shown it should be appreciated that personal protective equipment (PPE) is essential for getting close to such fires, and inhabitants are not equipped to be able to do this safely.

Figure 4-4: Firefighting efforts during the 2017 Imizamo Yethu fire

4.10 Fire suppressed

Once the bulk of the fire has been suppressed, the FD will continue with mopping up operations. Small embers may cause a fire to re-ignite so care must be taken to ensure that this cannot occur. When homes have collapsed, which typically happens, it becomes more difficult to locate smouldering embers. Hence, mopping up can take time.

An important aspect of the mopping up and restoration efforts are the fact that residents typically rebuild their homes extremely quickly. Figure 4-5 shows an image of a settlement which had just experienced a fire that destroyed almost 40 homes, and the image is taken approximately 40 minutes after the fire was suppressed. In this figure residents have already started taking their possessions back to their homes, and started reconstruction efforts soon thereafter, showing the very rapid reconstruction that occurs. Such actions by the community may make the efforts of responders more difficult in that inhabitants obstruct disaster management activities. It should be remembered that residents are typically desperate to ensure that they do not lose the piece of land that their home was located on, so will often not be willing to wait for formal processes to occur before they start rebuilding. Recovery is a dynamic process where the immediate needs of survivors must be balanced and aligned with long-term strategic objectives to build back better.

Figure 4-5: Photo showing an IS 40 minutes after a fire was suppressed, where firefighters are still busy with mopping up operations while residents are already bringing possessions back to their homes, and rebuilding would start shortly.

4.11 FD complete

Once the FD have completed their firefighting operations, they have finished mopping up and have handed over to other municipal organisations they will leave the site. Data must be collected regarding what happened at the fire, response efforts, resources used, number of homes affected and any other data that will be useful for understanding or preventing similar fires in the future. This data is captured using a standard Fire & Rescue Service Incident Report (FRSIR). Guidelines are currently being developed to gather fire incident data, beyond that required by the FRSIR, to assist with understanding such incidents and provide more details for evidence-based responses in the future.[44]

4.12 Support organisation involvement

If a fire has affected people's homes and municipal support is required, then various organisations become involved. This can occur in the following manner (which may vary between municipalities depending on what organisational structures are in place):

- After a large fire the municipal agencies responsible for Disaster Risk Management and Informal Settlement Management carry out assessments regarding the incident, the number of people affected, reconstruction efforts to be undertaken and the general needs of residents. Following larger fires, contractors, or municipal departments, may be required to clear the area. Services damaged by the fire will need to be restored.
- The local municipality, through their IS Management agency, is responsible for issuing disaster relief kits. These kits are discussed in Section 6.5.5.
- The Disaster Risk Management assessment is submitted to the SA Social Security Agency (SASSA) to guide relief efforts. SASSA is responsible for activating NGOs to assist with food parcels and support. SASSA can also provide stipends in the form of vouchers.

In many areas NGOs, local residents, nearby communities and other organisations are often involved in providing assistance and relief. This is an important part of post-fire recovery efforts. After a large and prominent fire the receiving and distribution of donations is a logistically complicated task requiring significant resources, community involvement, oversight and accountability. After the 2017 Imizamo Yethu fire, discussed in Chapter 5, one of the organisations who played an important role was a local NGO named Thula Thula. They played a vital role in trying to coordinate an incredibly chaotic situation. The delivery of large numbers of donations, storage requirements for donations, erratic distributions of gifts from people outside the community, demands from residents, people from outside the community who were not affected but try to obtain donations, and similar aspects makes such roles challenging.

4.13 Summary

From this chapter, it should be apparent that there are multiple steps that occur during a fire incident. The world's fastest fire truck is of little use if there is a delay in the notification of the fire department or if firefighters can't access the fire site. Multiple key stakeholders can contribute to improved fire response. The involvement of community members should not be overlooked as they are usually the first responders, and can significantly assist, or severely hinder, response efforts by the FD. The following chapter presents a case study on the Imizamo Yethu informal settlement fire disaster in 2017, to illustrate many of the aspects discussed above. It also sets the scene for considering how interventions can, and can't, address such events.


Image used permission of Justin Sullivan

5. Case study: The 2017 Imizamo Yethu Disaster

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The details below are a summary of a large, well-documented informal settlement fire incident to try to illustrate the complexity of real fire events and how they can affect thousands of people. This chapter can be used to place discussions in the previous chapters in context, and can also be used to evaluate if/how interventions might perform during such an incident (although it must be understood that this is an abnormally large event). The details are based upon by the work by Kahanji et al[42], which should be referred to for additional information, as only a summary is presented below.

5.1 Overview of the event

The March 2017 fire incident in Imizamo Yethu was one of the biggest fire incidents experienced to-date in South Africa, but there have been larger informal settlement fires in terms of size and the number of people affected. However, with this incident occurring in a highly visible area and over an extended period, with a large number of responders involved, good photographic imagery and response data has been obtained from it. Hence, fire spread rates and a fire incident timeline has been developed, which has not been possible for most previous fires. Also, firefighters from the Hout Bay and Constantia Fire Stations were interviewed to obtain additional information and confirm details.

The fire started at around midnight and took around 13.5 hours to extinguish, with 176 firefighters deployed from 20 fire stations to fight the blaze, along with 35 vehicles, 1 fixed-wing aircraft and 2 helicopters. It is estimated that around 9,700 people were displaced, and 4 people perished in the blaze. The cost of the incident to the City of Cape Town is a minimum of over R116 million (R17m for relief costs, R6.4 for operational costs, R60m for super-blocking post-fire efforts, R30m for emergency housing, and R2.6m for staff costs)[45], although it could be over R200 million depending on what direct and indirect costs are included. The cost of the fire to affected residents is not known. The area is still suffering from the effects of the incident as inhabitants seek to restore their homes and possessions. Table 5-1 summarises these details.

Chapter citation: Walls, R. and Smith, M. (2020), "5. Case study: The 2017 Imizamo Yethu Disaster", in Walls, R. (Ed.), *Fire Safety Engineering Guideline for Informal Settlements: Towards Practical Solutions for a Complex Problem in South Africa*, FireSUN Publications, Stellenbosch, pp. 63-70.

Table 5-1: A summary of vital figures and information of the March 2017 Imizamo Yethu fire [42]

Fatalities	4 deaths
Firefighter injuries	2 injuries
Structures destroyed	2,194
Displaced people	±9,700
Municipal cost	Minimum of R116 million, but possibly much higher
Firefighters deployed	176
Fire engines and equipment	22 fire engines, 6 water tenders, 1 skid, 6 support vehicles
Fire stations involved	20
Aircraft for aerial firefighting	1 fixed wing aircraft, 2 helicopters
(*Note*: at no single time were all the vehicles and personnel present simultaneously, due to: vehicles being refilled, arrival of personnel from different stations at different times, new teams taking over from teams who had been fighting for many hours, etc. The maximum number of fire engines at a single time was 12.)	

5.2 Fire incident details

Figure 5-1 presents an aerial image of Imizamo Yethu showing important factors regarding the incident, and the fire line at different times. The letters (A) to (E) correspond to specific times at which the fire line could be identified, and from which the fire spread rate could be determined, as presented in Table 5-2. The fire started sometime between 23:00 and 00:00, with start time depending on how long it took the fire to develop from ignition to flashover (see Chapter 3). It appears the inhabitants in the dwelling of origin perished, so there is no eyewitness account of how the fire started or how it spread initially. The first call to reach the Hout Bay fire station was recorded at 00:26, and a fire truck and water tender (tanker) were dispatched immediately, arriving at the nearest point to the fire at around 00:30. It is not clear why it took so long for calls to reach the fire station, but it is hypothesised that residents may have tried to fight the fire themselves for a period, took a while to detect the fire, or the incorrect number was called (e.g. 10111 as discussed in Section 6.3.2). Events from the initial stages of the incident are shown in Figure 5-2.

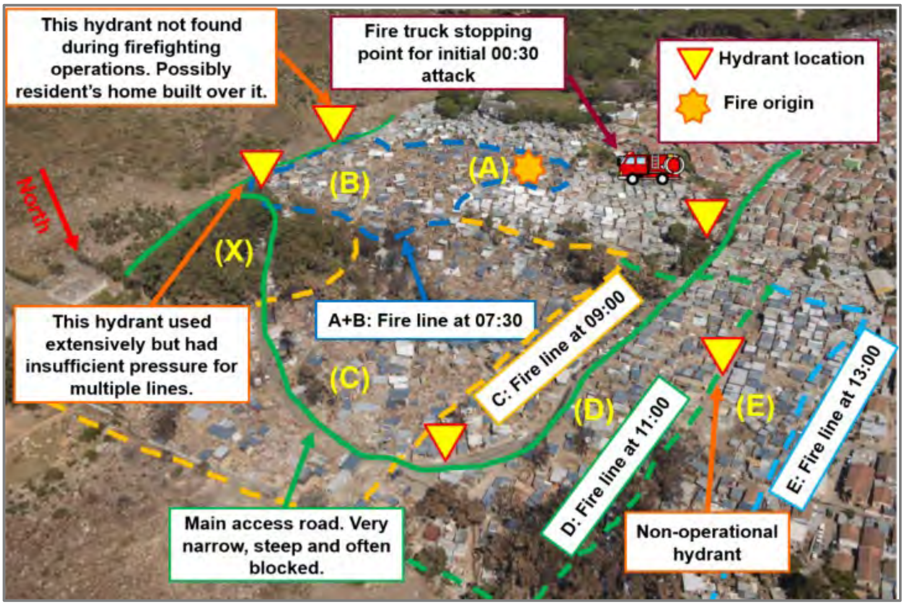

Figure 5-1: Aerial view of the settlement after the fire (underlay image used permission of Bruce Sutherland, City of Cape Town). The fire at different times, and details relating to firefighting operations, are shown, along with the access road (green). The homes within the burn scar (the dashed lines) have been reconstructed immediately after the fire.[42]

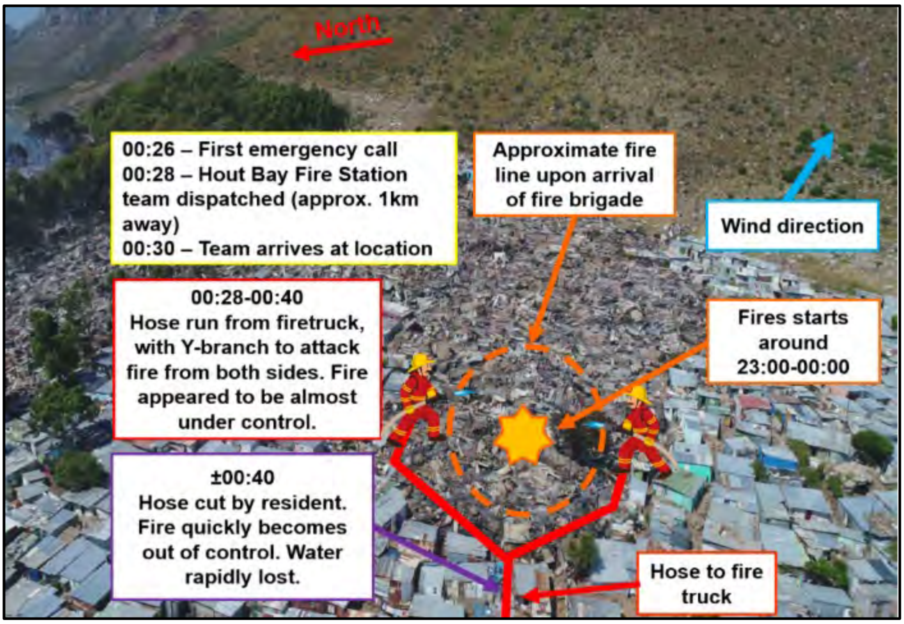

Figure 5-2: Fire spread and firefighter operations between ignition and 00:40 (Underlay image used permission of Bruce Sutherland, City of Cape Town) [42]

Table 5-2: Zones of Imizamo Yethu affected by the fire and corresponding numbers of structures affected. The number of structures burnt is approximated based on assuming a constant density of dwellings [42]

Name	Time	Area [m^2]	Approx. no. structures	Rate of home destruction [homes/minute]	Area rate of burn [m^2/hr]	Linear rate of burn [m/hr]
Zone A	23:30-01:00	3000	86	0.96	2000	30
Zone B	01:00-07:30	16200	463	1.2	2500	105
Zone C	07:30-09:00	28600	821	9.1	19100	140
Zone D	09:00-11:00	16500	472	3.9	8300	55
Zone E	11:00-13:00	12300	352	2.9	6200	55
TOTAL:		76600	2194			

By 00:40 firefighters felt that the fire was starting to become under control. However, at this time a resident cut the fire hose feeding the frontline firefighters. This was presumably done in an act of desperation, where a resident saw their home burning but not being extinguished (as the firefighters were tactically fighting other areas), and this was done such that the resident could redirect water onto their own home. This caused a significant delay in firefighting operations while a new hose had to be run and also resulted in a large loss of water. The fire then continued to grow and spread through the very dense settlement, reaching the edge of the settlement on the southern side (edge of Zone B). The settlement is on a hill with steep, rocky terrain, making firefighting efforts more difficult. The initial wind was from the North-East, but then changed to be a South-Westerly wind, which pushed the fire down the hill (i.e. from Zone B to E), forcing the firefighters to fight a new front. Had the wind direction not changed, it is possible that only around 500 homes would have been lost.

Figure 5-3: Images during the 2017 Imizamo Yethu showing the intensity of the blaze (Images used permission of Ryan Heydenrych, Vulcan Wildfire Management) [42]

From 02:00 to 07:00 additional support teams continued to arrive to fight the fire. The narrow, winding access road (shown in green in Figure 5-1), which was becoming filled with people and vehicles evacuating, along with residents' possessions, made access extremely difficult. Local hydrant infrastructure was used to supply water, although the main hydrant at the top was normally only sufficient for a single line at a time due to limited pressure. At around 07:30 the fireline reached a forest of Eucalyptus trees (blue gums) which proceeded to burn extremely quickly, and up to a great height. After the fire reached the Eucalyptus forest it burnt very quickly down the hill (whereas fires normally burn faster uphill), moving through Zone C. In 90 minutes around 820 homes were destroyed, which is more than 9 homes per minute. It is likely that flaming brands from the forest (see Section 3.1.2) caused many spot fires ahead of the main front, leading to the increased spread rate. Figure 5-3 shows the large fire front and flames engulfing double storey buildings at around 07:30. Throughout the aforementioned periods a number of additional hose lines also appear to have been cut.

From 09:00 to 13:00 aerial support assisted in the firefighting operations, although this is typically not done for normal urban fires. The water dropped from helicopter buckets, and rotor downdraughts, can potentially crush a structure and kill people, but the intensity of the fire necessitated these actions. The water bombing assisted in cooling the fire such that firefighters could slow its spread. The fire was eventually extinguished at around 13:00.

5.3 Factors that influenced this event

There are a large number of factors that influenced this event, and why such a large number of homes were lost. However, particular factors include:

- Homes were highly combustible and the settlement was densely populated.
- Interactions with residents, especially the cutting of hoses, hampered firefighting efforts early on.
- Narrow access routes made it difficult for vehicles to access the fire, and to go refill with water.
- Limited water pressure on hydrants reduced firefighting efforts. Also, some hydrants could not be found, possibly because residents had built their homes on top of them.
- The wind speed and change in direction pushed the fire through the densest parts of the settlement and made firefighting operations more difficult.
- The fire occurred during a relatively dry time of the year, at the end of the dry Cape summer period. Also, the area was in a drought at the time.
- It appears the forest created many firebrands/flaming embers which caused the fire to spread rapidly.
- There was a delay between when the fire started and when the first call was received by the local fire station.

5.4 Summary

From the discussions presented above, it can be seen that the Imizamo Yethu disaster was influenced by a variety of factors. However, many of these factors are also present in other informal settlements. Hence, similar fires will continue to happen in the future in other large, dense informal settlements with difficult access. In September 2020 another fire affected around 800 people in Imizamo Yethu. The complexities of the event discussed above should highlight how, as emphasised multiple times previously, a variety of solutions addressing all areas of fire safety are required to improve overall fire safety.

The recommendations presented throughout this document could contribute to reducing the probability and impact the fire incident presented in this chapter. Had the fire been stopped in the first dwelling the incident would never have even been reported. Conversely, it should be understood that even if certain interventions had been implemented in this settlement it does necessarily mean that the incident would never have occurred, but rather that the probability of the event occurring would have decreased. For instance, it is good when early warning devices are installed in people's homes, but had the dwelling of fire origin not had a detector (of if the battery was flat) it would have made little difference. Also, once the fire had developed and become intense construction products used to protect homes would have had a limited effect. Items placed internally on walls, or outside dwellings, would easily have ignited and still promoted fire spread. Had access for fire trucks, and the pressure on the hydrants, been better it is likely that the fire would not have destroyed as many homes, although the event would still have occurred.

Image used permission of Justin Sullivan

6. Interventions for Improving Fire Safety

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6.1 Considering fire safety interventions

Numerous fire safety interventions are available for improving fire safety in informal settlements (IS). However, each one has various advantages and disadvantages, or challenges and limitations. Also, an intervention that works well in one municipality/community, may not be as effective in another municipality/community, as introduced in previous chapters. Factors such as community cohesiveness, settlement location and access, existing infrastructure, available budget and the relationship between fire departments and communities influence the effectiveness of any intervention.

As introduced in Chapter 1, a variety of interventions can be implemented to improve fire safety. The broad categories considered in this document are: (a) active fire protection systems (require human or automatic interventions), (b) passive fire protection systems (permanently in place barriers or systems to prevent/reduce fire spread), and (c) interventions focussing on fire prevention/risk of ignition/preparedness. Specific items addressed are listed in Table 6-1, and depicted in Figure 6-1. Many of the discussions below are based upon research that has been conducted by the authors, and have been presented in different forms in the past.[9,39,46,47] However, before discussing active, passive and fire prevention interventions, it is important that the role of the community be discussed.

At the end of each section discussed below a summary of important points is presented to emphasise key points (given by the orange text in a box).

Chapter citation: Walls, R. (2020), "6. Interventions for Improving Fire Safety", in Walls, R. (Ed.), *Fire Safety Engineering Guideline for Informal Settlements: Towards Practical Solutions for a Complex Problem in South Africa*, FireSUN Publications, Stellenbosch, pp. 71-111.

Table 6-1: List of examples of active protection, passive protection and fire prevention / risk of ignition strategies that can be considered.

Active fire protection	Passive fire protection	Fire prevention / risk of ignition / preparedness
• Fire departments (including strategies, training, mobile fire fighting units, aerial support, fire department number awareness campaigns, improving relationships with communities, etc.) • National unified emergency number • Water/hydrant infrastructure • Suppression products and systems for community members: extinguishers, throwing products, blankets, bucket brigades, dry firefighting methods. • Smoke and fire alarms • Community response teams	• Reblocking / area reconfiguration • Building code application and enforcement • Fire walls/fire breaks • Provision of roads and pathways • Improved construction materials for new homes • Retrofitting of existing homes with fire resistant products (boards, paints, etc.) • Provision of escape from homes	• Mapping of areas to analyse risk, determine available facilities, prepare for disasters, analyse fire access routes, etc. • Electrification • Improved cooking, lighting and heating interventions • Fire safety kits • Education campaigns • Medical training for burn treatment, and the provision of medical facilities.

Image used permission of Justin Sullivan

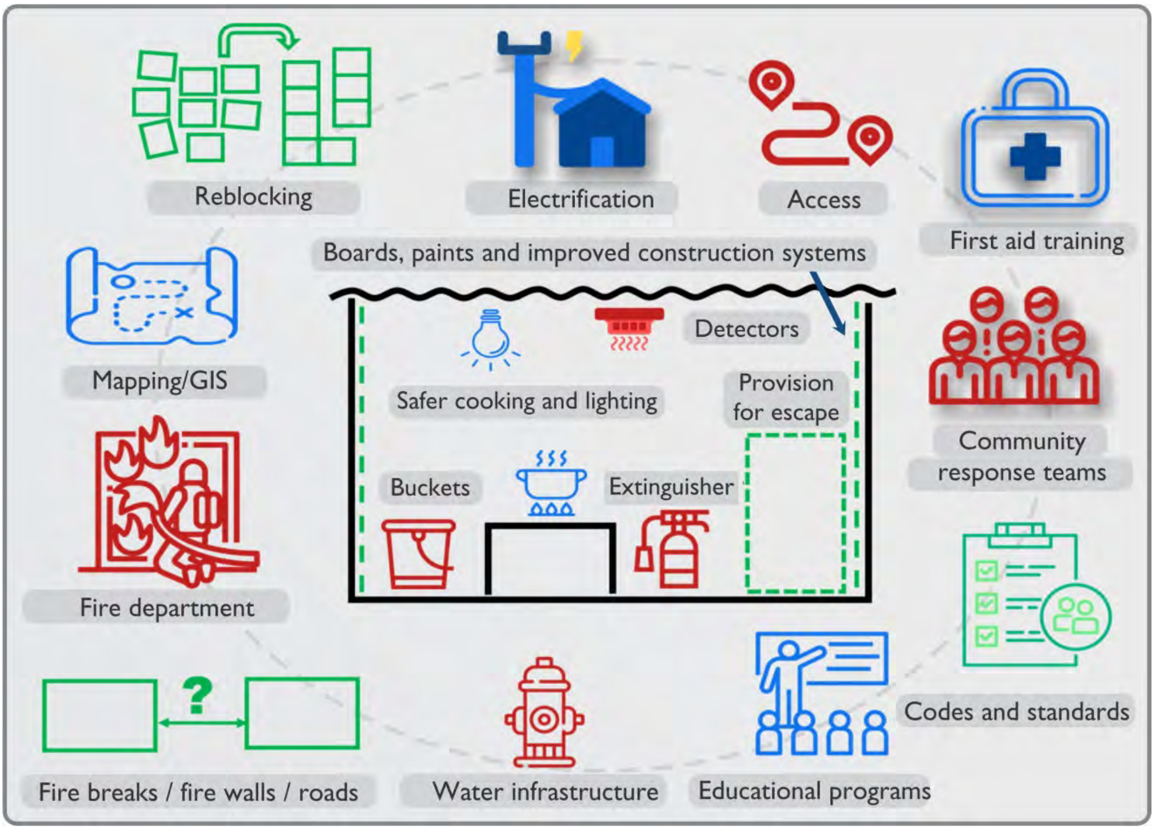

Figure 6-1: Illustration of various fire safety interventions and systems that can be considered, with active fire protection interventions shown in red, passive fire protection interventions shown in green, and fire prevention/risk of ignition/preparedness interventions shown in blue.

6.2 Community Activities – Getting inhabitants positively involved

A community's involvement should not be overlooked as they play a pivotal role and can assist in many ways. In this chapter many different means of suppressing fires and improving fire safety are discussed. However, a simple summary is presented here to give a list of tasks the inhabitants could be involved with. Figure 6-2 shows a flowchart of decisions and activities that community members can engage with. Once a fire has been found inhabitants should ask "Can I put this fire out?"

- "Yes"- If the fire is small, and the equipment needed is available they can immediately suppress it.

- "Maybe"- If the inhabitant can possibly put the fire out they should immediately start doing this whilst signalling (yelling) for other community members to call the fire department (FD).

- "No" – Then call the FD immediately.

For the latter cases community members can then start carrying out the tasks discussed below (excluding the "Preparedness" items, which ideally should be in place already).

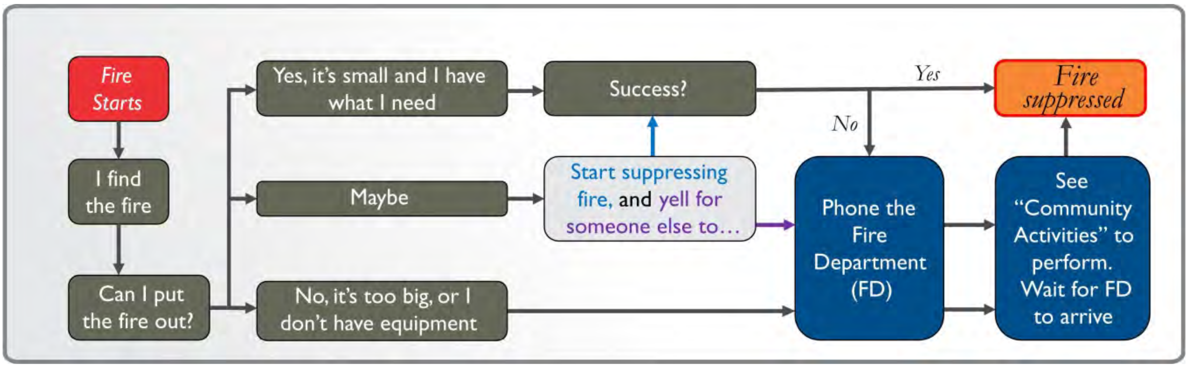

Figure 6-2: Flowchart showing decisions for an inhabitant who finds a fire and needs to figure out how to respond to it.

The following are specific activities that IS inhabitants can undertake before a fire (preparedness), immediately after a fire has been found, when a fire is potentially coming towards your home, and after an incident. At no point should residents undertake activities which would endanger themselves. Residents should always seek to evacuate rather than risk losing their lives or be severely injured. It should be understood that fires can move very fast and be unpredictable (especially if the wind suddenly changes).

- ***Preparedness***

  - A community preparedness plan should be developed for the area, which can be broken down into smaller neighbourhood blocks. This will assist in guiding the activities of individuals.

  - Have a family emergency plan prepared such that family members know what to do, and where to go.

  - Clear combustible items next to homes away from them, such as piles of wood, plastic, cardboard or tyres.

- Have more than one way of escaping from a home and make sure everyone in the house knows about it (see Section 6.4.5).
- Have a "grab bag" with documents, medicines and valuables that can be taken when exiting the structure.
- Have a printout/laminated page and other items (e.g. keyrings) with emergency numbers on them.

- *After fire has started and been identified*
  - Notify other residents.
  - Alert the fire department. It is beneficial to have details such as street addresses or landmarks nearby to assist firefighters in locating the fire site.
  - Carry out basic firefighting activities using bucket brigades, thick blankets or by collapsing dwellings. However, inhabitants should not put their lives at risk.
  - Evacuate the area and do not come back to fetch possessions.
  - Clear access routes to allow for fire truck access.
  - Guide the fire department to the fire site from the edge of a settlement, as discussed below.
  - During firefighting operations notify firefighters if flare-ups occur (due to spotting or from smouldering embers that cause re-ignition)
  - Protect firefighters and municipal agencies from antagonistic community members.
  - If possible, try to see where the fire is and which direction it is moving in. However, with changes in wind direction fire direction can change quickly.
  - Keep fire hydrants clear, and help firefighters in locating them.
  - Put on any protective clothing available, or the most protective clothing owned. Avoid synthetic materials (e.g. nylon). Leather jackets, workers' overhauls and thick cotton materials are typically most suitable.
  - If your home and family are not in danger then assist other community members.
  - Obey any instructions from firefighters, police or municipal officials.

- ***Preparing your home when a fire is coming***

  - Close all doors and windows of homes to reduce the chance of homes being ignited by flames, and to reduce the chance of embers getting into homes.

  - Pull combustible curtains and cladding off the walls or windows, and move these into the middle of a room such that they cannot be ignited as easily. Also, move any combustible furniture into the middle of rooms.

  - Turn off electrical power and appliances.

  - Turn off any gas supplies or appliances, and if possible, remove gas cylinders, paraffin stoves/cookers/heaters and paraffin bottles, placing them as far as possible from the fire.

  - Have important documents and valuable possessions in a bag that can be quickly removed.

  - Clear any combustible items next to homes away. If something next to your home catches fire, your home is likely to catch fire.

- ***Immediately after the fire***

  - Make arrangements, such as for temporary shelter, for after the event.

  - Work with municipal departments, Disaster Risk Management and NGOs during recovery efforts. Where possible, do not start rebuilding immediately as the municipality may need to come in and clear the site.

  - If possible try to rebuild homes in a more ordered way, with better road and pathway access (i.e. some level of reblocking. However, normally this is not feasible).

  - Community leaders should assist with enumeration efforts to count the number of affected homes and people.

  - Work with NGOs and organisations providing relief. Community leaders should try ensure that donations are fairly distributed.

  - Assist injured people with getting medical attention.

6.3 Active Fire Protection Interventions

6.3.1 Fire departments

Historically fire departments have played a very important role in fire safety. In many parts of the world they came about to protect insured interests such as warehouses and ports.[48] The presence of a well-resourced fire department coupled to efficient detection and alarm systems can reduce the number of uncontrolled fires by orders of magnitude.[49] In terms of IS fires, fire departments will always play a key role, as once more than one home has reached flashover (see Chapter 3), and the fire is starting to spread in a denser settlement, the community will not be able to suppress the fire themselves. However, in remote communities and areas which have almost no access (along with many poor countries around the world) it is possible that the fire department may not be able to respond to fires, meaning that community members will be solely responsible for firefighting efforts.

Many key aspects need to be considered when discussing fire service intervention in ISs:

- What resources does the fire department have relative to the number of homes/structures/businesses, types of fires and frequency of fires they have to respond to?
- What is the relationship between the fire department and communities?
- Can the vehicles of the department access the fires in an area?
- Do the inhabitants know the correct fire department number?
- What infrastructure is available to supply water from? How far would a truck need to drive if they cannot access additional water at the fire site?

Once a call has been relayed to a fire department, the response to an IS fire may vary between municipalities. However, typically a fire station will send a single truck, a water tanker and a team of firefighters to the incident. At the same time another one or two support trucks, and a water tanker, are called from neighbouring stations. The distance between stations and the fire location can affect the time for backup to be received. If it is determined that the fire cannot be brought under control by these resources more support is progressively dispatched to assist.

Although it is difficult to quantify the impact of fire department intervention, many factors should be considered to improve fire safety in settlements. Firstly, it must be ensured that vehicles can access the fire location. Items that prevent larger vehicles from being able to go into ISs include low hanging electrical lines. Figure 6-14 shows various extension cords and illegal connections in a settlement that would make access difficult. Also, inhabitants often incrementally upgrade and expand their dwellings over time, especially when family sizes grow, meaning that homes may extend into access routes. Inhabitants may park cars along access roads (especially during popular events such as big televised soccer games), making access by larger emergency vehicles almost impossible in such instances.

- *Relationship between fire department and community*

Unfortunately, in many instances poor relationships exist between communities and fire departments, leading to firefighters having rocks or bricks thrown at them when they arrive. This breakdown in relationships can occur due to a variety of reason: (a) historical issues, (b) political tensions, (c) community perceptions regarding poor response and service provision (whether true or untrue, and possibly related to incorrect numbers being phoned, fire departments not even being phoned, or lack of resources at the local fire department), (d) malicious intent from community members who incite others, (e) etc.

Further research is required to identify the many factors that influence these relationships, and how to improve them. Nevertheless, significant effort is required to improve relationships, as this will improve fire safety. As an anecdotal example of the importance of good community relations: due to improved relationships in one settlement during a fire incident in 2019 the residents assisted by clearing the road to allow for access by firefighters. They also assisted in directing the firefighters to the location of the fire, improving the response time and reducing the number of homes affected. Conversely, an analysis of the 2017 Imizamo Yethu fire,[42] discussed in Chapter 5, showed that during the incident residents cut fire hoses. This likely resulted in the fire spreading much further, possibly destroying hundreds of additional homes. It is hypothesised that the reason residents cut the hoses was due to desperation to save their own homes, as firefighters were strategically fighting to suppress the fire to prevent spread, but were not addressing the hose-cutting-residents' specific homes which were burning down.

Potential methods for improving relationships with communities may be to:

(a) Have a regular positive presence in the community through vehicle patrols or firefighters being seen.

(b) Engaging with community leaders, NGOs, religious organisations or other organisations to find ways of improving fire safety, and to get feedback from the community.

(c) Carrying out community training initiatives.

(d) Marketing the local fire department number to improve response time.

(e) Being involved with the roll-out of initiatives such as fire safety kits, smoke alarms, etc.

(f) Try to get sponsorships to roll-out fire safety initiatives.

(g) Improve response times through (i) employing different strategies, (ii) the use of suitable vehicles, (iii) mapping areas to ensure that firefighters know what infrastructure is available and how to reach fires as fast as possible, (iv) building more fire stations (only considered on city planning levels), (v) having more resources available (but normally constrained by budgets), etc.

(h) The Fire Department can have monthly information sharing meetings with communities with the following objectives: (i) FD shares information on fires that have occurred during the month, (ii) fire causes, (iii) patterns when fires occur, (iv) positives (such as fires extinguished, roads cleared by communities, etc.), the ease of getting to the scene, crowd perception, and (v) any other challenges experienced by the FD. Communities share information on (i) fires occurring and extinguished by community, (ii) effectivetivensss of systems and areas for improvement (iii) concerns or any problems experienced e.g. the call-out system.

(i) Fire department shares with community fire projections for the month giving information such as the days fires are likely to occur (weather forecasting, weekend paydays, soccer matches, etc.) to put the community teams on alert, whilst the community shares information such as potential hostilities or flashpoints for the month. Meetings/engagements between interested parties should be conducted regularly (in the same way as Community Police Forums do) and not be a once-off event where parties leave the community once 'completed'.

(j) Discuss and analyse fire causes to prevent further occurrences.

Through ongoing community engagement, the active and passive interventions and fire prevention systems should be evaluated and improved to ensure maximum effectiveness. The goal of these evaluations is to work towards a common goal – to prevent fires and to minimise the impact of fires that do occur. To implement the items discussed above additional resources may need to be provided to FDs as such activities can be intensive in terms of staff time.

- *Training of firefighters*

The training firefighters currently typically undergo in South Africa is more than sufficient for ensuring that they can address the technical aspects of suppressing fires in general. However, depending on the municipality and the level of training firefighters have received, the following training may be beneficial:

- Developing methods for engaging with communities, and working in collaboration with them before and during a fire. This follows on from discussions above.

- Employing GIS systems (e.g. satellite images, services layouts etc.) to plan responses, determine how to access different parts of settlements, and identify high risk areas.

- Ensuring firefighter safety during operations, especially when inhabitants are antagonistic.

- Modern firefighter training is adopting virtual reality systems which allow for training in difficult environments. It may be possible to create suitable informal settlement simulations (that include factors such as residents cutting hoses and difficult to locate hydrants) and use these for training firefighters. These will not be perfect and many real-world factors will be difficult to include, but still may be beneficial.

Fire departments are key to overall fire safety, both in prevention and response. There are opportunities to develop response plans for responding to specific settlements. Keep access roads clear to allow for fire truck access. Improve relationships between fire departments and communities, and get communities involved in assisting their work. Fire departments should look at different strategies for responding to fires.

6.3.2 Community response teams

Empowering and equipping community members to safely respond to IS fires is important as community members are almost always the first to respond to fires. It is known that many fires are never reported to the fire department because they are managed by the community, and further firefighting support is not needed. Research is needed into the methods of firefighting used to manage these incidents, and into informal training that takes place between community members with regards to fire safety, including fire prevention and response. With formal training and firefighting equipment, community members can likely extinguish more small fires, and reduce the impact or even contain a fire until the fire department arrives. Community Emergency Response Teams (CERT) have been trained by some fire services.[50]

Figure 6-3: Community members being trained to respond for fires by the Johannesburg EMS (Image used permission of Rodney Eksteen, Oklahoma State University)

The establishment of CERT teams requires support and coordination. Ongoing training is also required as team members may move, or become inactive over time. If stipends are provided to members this may serve as job creation and the positions may become competitive. The selection process for CERT members should include an assessment of the likelihood a person will be willing, or able, to respond during a real emergency. Holding members who do not respond to account is difficult, meaning that there is limited control on activities, even when stipends are provided. If equipment is supplied to CERT teams, processes should be in place to ensure that this is inspected on a regular basis, as items may expire, go missing or be used personally by team members. Also, a topic requiring further investigation is that of liability, as if a person is trained by a municipality to respond to a fire, is supplied with equipment, and then is hurt during an incident, could the individual or the municipality be held liable?

The availability of trained community members assists in providing rapid response during incidents. The establishment of teams requires ongoing coordination and support.

6.3.3 National unified emergency number

[At the time of publishing this report South Africa was in the process of adopting a single unified emergency number for all types of emergencies. When that has been implemented the discussions below should be ignored, and community members should be instructed to contact that single number.]

An ongoing problem faced with responding to IS fires is: which phone number should be phoned in case of emergency? *With the rate that fires spread in informal settlements, a delay in response of 10 minutes may result in 5-30 extra homes being on fire, meaning that phoning the correct number, and phoning it as soon as possible, is vitally important.* In South Africa, the number for the fire department from landlines is 107, but this does not work from cellphones. Almost all residents in ISs use cellphones for communication. The cellphone network number for emergencies is 112. However, various municipalities provide their ten digit disaster management call centre number, such as 021-480-7700 for Cape Town, with each municipality having a different number. A method for improving fire department response times is by widely advertising the contact number suitable for the local fire department. This can be done through posters, banners, stickers on items, flyers, printed t-shirts, and various other methods.

Currently, the phone number of the police flying squad, 10111, is regularly phoned by residents. The problem is that the police are obliged to first attend to the incident, check that a fire is present, and then relay the message to the fire department. This results in significant delays, potentially meaning that many more homes are burnt out before the fire department can arrive.

It would be highly beneficial if a single number, linked to a well-managed call centre, could be dialled in case of emergency, to improve fire department response time and overall operational efficiency. It is understood that various political, economic, geographical and operational issues influence this decision. Nevertheless, it is something that we should strive towards as a country, as this will assist in protecting inhabitants and reducing losses.

Publicise the local fire department number (and NOT 10111 for fire). National goal: Have a single, national, unified emergency number.

6.3.4 Water / hydrant infrastructure

Water is essential for suppressing most fires. A typical fire truck can carry around 3000 litres of water, whilst a water tanker can carry around 6000 litres. Once water supplies have been used vehicles will need to find the nearest water source to fill-up. During a big fire, when roads become congested with evacuating people and inhabitants' possessions, refilling vehicles adds significant delays to firefighting efforts, as trucks can be gone for significant periods if they have to drive a long way to the nearest supply point. Fire hydrants are very important for providing water during firefighting operations. However, ISs are normally built on the outskirts of cities, and are often not serviced by bulk water infrastructure.[51] Firefighters have also reported not being able to find hydrants due to homes being built over them,[52] and anecdotal feedback indicates that in some cases residents with a hydrant in their home may sell water to other members in the community. Research has shown that in South Africa sometimes as little as 8.6% of all fires (including formal, wildland, etc.) are suppressed with hydrants, whereas the majority required pre-filled tankers.[53] Further research is required to understand hydrant usage specific to informal settlements.

Where hydrants are available their position should be mapped and known by the local fire station members. These should be kept in operation and serviced regularly. If possible, community leadership should try to prevent people from damaging hydrants or building their homes on top of them. Community leadership should be made aware of who to contact if it is noticed that hydrants have been damaged. If no hydrants are present fire departments must also be aware of this. (Note: Often hydrants have been geo-located in GIS software and the fire department has access to such information).

Map and communicate where the local hydrants are. Prevent community members from vandalising hydrants, or from building their homes on top of them. Make community leaders aware of who they should report hydrant damage to. Ensure local hydrants are in working order.

6.3.5 Suppression products and techniques for community members

By understanding how fast a fire can develop in an IS it must be realised that there is no way for a fire department to respond to a fire before it has engulfed many homes. Hence, community members should, where possible, be able to put out small fires. There are various options regarding this:

- Bucket brigades
- Buckets of sand
- Fire extinguishers
- Proprietary throwable extinguishing products
- Dry firefighting techniques

When considering fire suppression there are different classifications of fires, as listed in Table 6-2, which also provides simple means of remembering the classifications. In informal settlements much of the contents of homes, and construction materials could be considered as Class A fires. However, paraffin stove fires and cooking oil fires would be considered Class B and Class F fires.

Table 6-2: Classification of fires (along with simple ways of remembering the classifications)

Classification	Description
Class A	Fires which comprise of organic combustible solids such as wood, paper, rubber, fabric and plastics which do not melt (Class A fires leave Ash)
Class B	Fires which comprise of combustible liquids or liquefiable solids such as petroleum, oil and paints (excluding cooking oils and fats) (Class B fires can Boil)
Class C	Electrical fires (Class C fires involve Circuits and Current)
Class D	Fires which comprise of combustible metals such as magnesium, lithium etc. (Class D fires involve Dangerous metals)
Class F	Fires which involve cooking oils and fats (Class F fires include Fats)

- ***Bucket brigades***

When a fire occurs in an IS, community members often try to suppress the fire using buckets of water. If there is a distance between the water source and fire location a “bucket brigade” can form, which is a series of individuals passing buckets down the line to transport the water to the fire.

Figure 6-4: Sponsored bucket brigade roll-out and training in a settlement, facilitated by Ukuvuka Operation Firestop (picture used permission of Rodney Eksteen, Oklahoma State University)

Testing has been conducted on full-scale IS dwellings (ISD) to investigate the usage of water buckets, and how efficient they are.[54] Figure 6-5 shows the time-temperature graph from a full-scale experiment on a 2.4 x 3.6 x 2.4 m high dwelling with 25 kg/m^2 of timber (Refer to Section 3.1.1 which explains such graphs). During the experiment 9 buckets, with approximately 8 litres in each, were required to suppress the fire, once it had reached flashover, and this was done in around 3 minutes. Sufficient water needs to be applied to ensure that the temperature in the room is well below the ignition temperature of the materials that are burning, and all flames are suppressed. Extra water is also required at the end to ensure that all embers are fully put out once flames are gone, as fires can flare up again if embers are not addressed.

During testing it was observed that water was typically more efficient at reducing temperature than the proprietary throwable products discussed below. Also, residents tend to use buckets daily so they are more available. For a typical home it is estimated that somewhere between 7 and 15 buckets of water, with 8 litres in each, would suppress most home fires. This would depend on the size of the dwelling, accuracy of application of water, speed of refilling buckets, shape of the items burning, size of the dwelling, type of material burning and other similar factors.

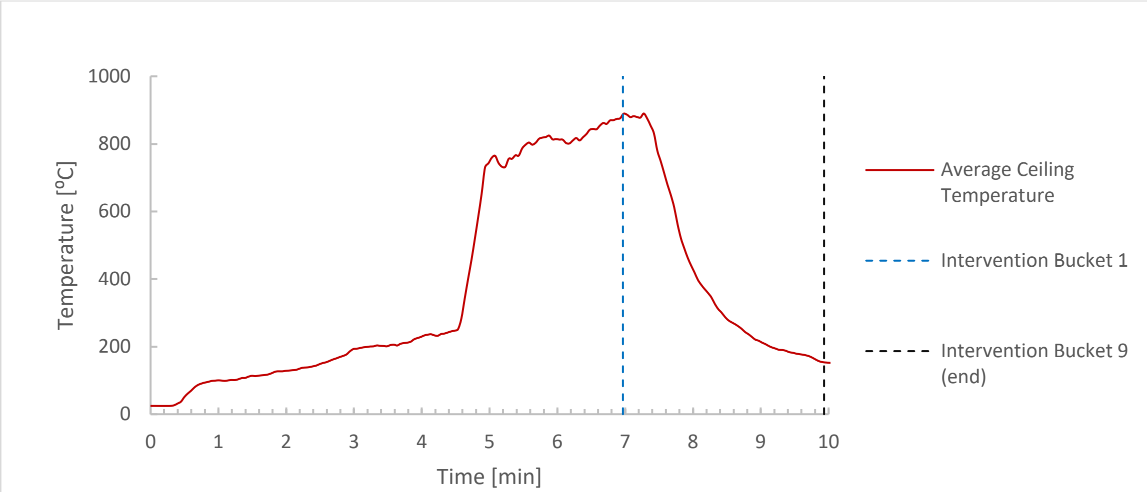

Figure 6-5: Time-temperature curve during a full-scale experiment to investigate the use of water buckets in suppressing an informal settlement dwelling fire, with nine buckets of water being applied [54] (Note that the delay in temperature decline between the temperature and the application of Bucket 1 occurs because the water is applied onto the fire at floor level, but temperatures are measured at the ceiling)

Buckets are typically effective at putting out fires. Challenges in terms of bucket usage include ensuring that sufficient water is available from local standpipes, and ensuring that these are not too far from fires. Once fires become large (i.e. multiple homes involved) it can become difficult for residents without protective gear to get close enough to fires to be effective. Also, in larger fires many people start filling buckets from any available supply, meaning that water pressure drops and it takes a while to fill each bucket, thus slowing the response.

Training can be offered to communities to carry out bucket brigade suppression activities, at which time details regarding oil and electrical fires can also be addressed (see below). It is currently being investigated whether printing the local fire department number on the sides of buckets and distributing these to the community will assist in (a) promoting better community relationships, (b) providing a tool for extinguishing fires, and (c) publicising the fire department number (although this remains to be seen). It is acknowledged that buckets may be broken, sold or used for other purposes, hence may not necessarily be available when a fire breaks out. If buckets were distributed to a community such distribution would need to be done at regular intervals (e.g. every few years), especially in a highly transient community.

Residents who have buckets in their homes could be encouraged to keep water in them overnight, such that if a fire breaks out there is more water immediately available. However, this can lead to other dangers, such as small children drowning in buckets, health problems associated with standing water, buckets being knocked over inside homes, and similar issues.

NOTE: water is *not* suitable for putting out oil or electrical fires (see Annex A for further details regarding both instances). It is very dangerous to put water onto an oil fire as the sudden vaporisation of the water can propel the flaming oil into the air and cause the fire to rapidly spread. Sand or thick blankets should rather be used to suppress such fires. Similarly, applying water to an electrical fire can cause electrocution.

Buckets of water are typically effective for supressing fires. It must be ensured that enough water is available for filling buckets. Distributing buckets with the local fire department number on it may be effective in both providing basic firefighter tools and advertising the number. Community training regarding suppressing oil and electrical fires can accompany a bucket brigade roll-out.

- *Proprietary throwable extinguishing products*

Various products are available on the market that can be used to suppress fires. Figure 6-6 shows, as an example, (left) a plastic ampoule contains an extinguishing agent, which can be thrown into a fire. Also shown is a ball (middle and right) that contains a dry chemical powder that is a grenade style product which effectively explodes in a fire and disperses the powder to suppress a fire.

Several important questions need to be asked when selecting such interventions:

- Has the product been tested and certified by independent bodies, and what standards has it been tested in accordance with?
- What is the maximum fire size the device can suppress? (It is not easy to measure fire size as many factors influence this)
- What conditions need to exist for the product to be effective (e.g. maximum size of enclosure/compartment)?
- How much does the device cost?
- What is the shelf-life of the product, and once it has expired how must it be disposed of?
- How accurately would you need to throw the product for it to be effective?
- Will training be provided to the community regarding how they should be used?

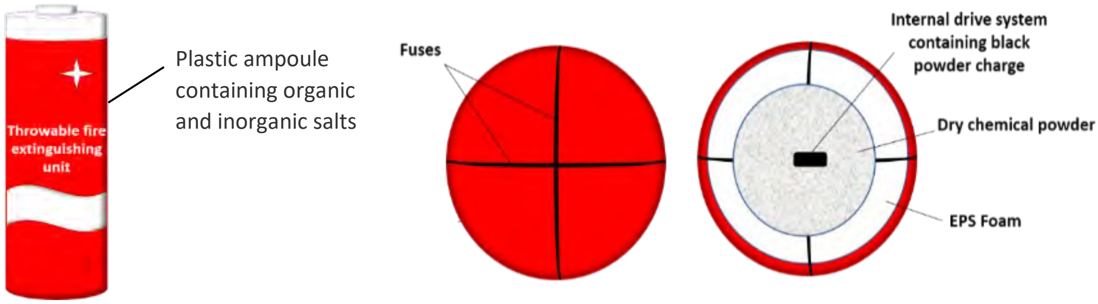

Figure 6-6: (Left) Example of a throwable ampoule, (Middle and Right) Example of throwable dry chemical power unit showing the outer appearance (middle) and cross-section (right). Such products may be suitable for small fires, but are often ineffective for post-flashover fires. [54]

Many products on the market have been tested and certified, but are typically only suitable for smaller fires (e.g. it will note the product can suppress a fire in a space of 3m^3, whereas a home could easily be 20-75 m^3). For small fires, such as a pot of oil that catches fires, or the edge of a curtain that catches fire from a candle, these products may be suitable, and could be employed for such instances. However, once flashover has occurred they are typically far less ineffective. Suppression products will typically work by either cooling the fire (removing the heat) or by preventing the chemical combustion process. It is possible to smother fires with fire blankets or heavy materials, although in larger fires it is often difficult to use oxygen depletion to suppress a fire. Testing as discussed above has shown that to suppress a post-flashover fire in a small IS home fire around 60-120 litres of water are needed when applied by buckets in a relatively short period of time (possibly more, depending on many factors especially that of flowrate, i.e. how many litres per minute can be applied). Hence, a suppression product weighing 0.5-2kg will have almost no cooling effect. Products that work by preventing the combustion reaction may be effective at stopping the fire locally to where the product lands. However, temperatures in a post-flashover dwelling are normally around 700-1000°C, meaning that the materials are above their spontaneous ignition temperatures. Hence, as soon as the effect of the product stops (especially due to the turbulent air flow in the dwelling) the fire comes back almost immediately to the area that was suppressed. During testing previously conducted, up to 24 units of a product were thrown into a post-flashover dwelling without having any effect.[54] The products shown in Figure 6-6 were found to be ineffective for *post-flashover* fires for such reasons.[54,55]

The cost of proprietary products can vary from R200 to R1000 per unit, depending on what is used. Hence, when supplying units to each person in a community it can become very expensive. Also, units will often expire with time, and will then need to be replaced every few years. In theory, each resident would need a unit as suppression must be done soon after ignition while fires are still small, and products are still suitable. For some of the products, tested by fire departments it has been noted that the person using the product must have a good aim, especially when the fire is small. If the unit is not thrown directly into the fire, or not thrown hard enough for the unit to explode, it will not be effective. Furthermore, the units supplied to residents may not be stored in a suitable place, meaning that they are not accessible in a real fire. Also, if the units have any value they might be sold.

Overall, there should be significant caution when purchasing proprietary suppression products for community fire protection. If a product is relatively simple and cheap, or is only required for small fires soon after they start, they may be effective. Any roll-out should be accompanied by formal testing and community training. A simple method of benchmarking suppression products specifically for informal settlements is discussed in detail by Löffel & Walls. [54]

Proprietary products may be suitable for smaller fires. Their effectiveness should be tested, and a cost-benefit analysis done. For larger fires they are typically not effective. Products often have a shelf-life and must be replaced at certain yearly intervals.

- ***Fire extinguishers***

Fire extinguishers are extensively used in homes, commercial centres and industrial complexes. Various testing standards exist for ensuring that they are suitable. For use in ISs the following should be considered:

- How many extinguishers, and what type, can be supplied, and where will these be located?
- Will people be trained to use the extinguishers?
- Who will be responsible for maintaining them, as they require regular maintenance and refilling after any usage? This can become a long-term expense.
- How big should the extinguishers supplied be?
- Is it likely that the extinguishers will be sold, damaged or misused?

Figure 6-7: Examples of different fire extinguishers showing (Left) a 4.5kg DCP extinguisher, (Middle) a 9kg DCP extinguisher, and (Right) a 2kg CO_2 extinguisher. (Images used permission of the Centa Group)

An operational fire extinguisher used by a competent person can be very effective in suppressing fires. A post-flashover fire in a 2.4x3.6m home filled with 25kg/m^2 of timber was almost fully suppressed with a single 9kg dry chemical powder (DCP) extinguisher, except that for the final efforts a second extinguisher was needed and partially used.[54] Prices on extinguishers range but are around R300-R400 for a 4.5kg DCP unit, around R450-R600 for a 9kg DCP unit (2020 prices). A DCP extinguisher is suitable for Class A, B and C fires. Carbon dioxide (CO_2) extinguishers are effective for Class B and C fires, but are typically more expensive at around R1000 for a 5kg unit. Hence, DCP extinguishers would generally be better for general IS usage. Furthermore, it should be ensured that extinguishers are correctly certified, as many products have not been tested and certified. Water fire extinguishers can be used for Class A fires and cost around R650 for a 9L extinguisher.

Anecdotal feedback has indicated that extinguishers provided to communities can get lost or stolen. Some initiatives have tried to place these at central locations with responsible people overseeing them (e.g. at community centres, shops, crèches, etc.). A budget would need to be allocated to ongoing maintenance and annual testing of such extinguishers.

Extinguishers are typically effective for fire suppression, but would need to be located with responsible and available community members. They require ongoing maintenance, which must be budgeted for. Training is required for people who will be using the extinguishers. Ensure that products are correctly certified.

- *Dry firefighting methods*

As introduced in Chapter 2, if a fire's source of fuel is removed it can stop the fire from spreading. One way to do this is through dry firefighting methods, whereby homes are physically broken down ahead of a spreading fire, or combustible items are removed to reduce spread. This is sometimes referred to as "flattening". These techniques have historically been used in countries such as Japan.[48] It has been observed in South Africa during IS fires as well, with community members being involved in strategically demolishing structures, as shown in Figure 6-8 which was taken during the 2017 Imizamo Yethu fire. In South Africa, large military-type vehicles, called Casspirs, have historically been used to demolish structures and prevent spread. This approach is no longer used, and community members may become hostile to the use of vehicles in their settlement (and understandably so), if they think their homes are being unnecessarily destroyed.

Figure 6-8: Dry firefighting techniques being employed by a resident trying to demolish his home to prevent spread and possibly save the construction materials. (Image used permission of Justin Sullivan)

There are various challenges associated with dry firefighting methods. The construction of each home varies, and it can require significant effort to knock-down a well-built dwelling. Furthermore, there are safety risks associated with demolishing structures manually or using vehicles, as people could be trapped inside or could be injured by falling debris.

Dry firefighting techniques can provide a fuel break to reduce fire spread, but homes are often difficult to knock down.

6.3.6 Sprinkler systems

Sprinklers are commonly used in building around the world, as they can be effective in fire containment and extinguishment. Sprinklers significantly reduce the chance of a fire becoming fully-developed.[56] However, sprinkler systems require a constant water supply at a relatively high pressure, need ongoing testing and maintenance, can easily be vandalised, and are expensive to implement. They are therefore not suitable for ISs. Additionally, sprinkler systems would need to expandable to accommodate growing settlements. With limited access to water infrastructure in IS, sprinkler systems may be tapped for daily water usage, meaning they may not be effective during a fire.

6.3.7 Smoke and fire alarms

Based on discussions regarding how fast fires develop (see Chapter 3), fire departments can't attend to a fire before a dwelling is fully involved to perform search and rescue operations. Hence, the use of early warning systems is essential for saving people and homes before fires can develop and spread. Thus, the use of early warning systems should be encouraged. However, there is no perfect technology currently available for ISs, and all devices have different advantages/strengths and disadvantages/limitations. These should be thoroughly understood before selecting any device for usage. The primary considerations that should be addressed include:

1) What kind of fire should be detected (smouldering vs. flaming vs. temperature rise)? Most people who die in fires die from smoke inhalation, meaning that it is beneficial to detect smouldering fires from a life safety perspective. In most formal environments only smoke detectors are considered life safety devices.

2) How sensitive is the device to nuisance alarms? Higher sensitivity leads to more false alarms. False alarms can annoy inhabitants, and their neighbours, to the point that devices are removed or deactivated if they experience too many false alarms. Hence, a balance between sensitivity, and reduced false alarms, is a challenge. Discussions are provided below on the causes of false/nuisance alarms.

3) How long does the battery of the device last, and what type of battery is used? Residents may not maintain devices or be willing/able to pay for new batteries. Hence, long-life battery systems should be considered (e.g. 10 year lithium batteries). However, many of the long-life batteries are sealed into the devices, so the entire device must be replaced once the battery has depleted. When 9V batteries are used residents can remove them and use them in other devices, such as TV remotes, meaning that detectors may be installed but not active.

4) Can residents stop false alarms, for example, by using a hush button? This reduces the impact of false alarms, as residents can stop alarms from going off, by reducing the sensitivity for a period of time.

5) Various other considerations include: Are devices wirelessly linked together? Do devices automatically notify authorities, or send a message to a central control centre or to household residents/community members? What challenges are there regarding privacy and knowing the location of residents? etc.

Technologies that are currently available for early detection include:

(a) Ionisation smoke alarms

(b) Photo-electric smoke alarms

(c) Rate-of-rise alarms

(d) Carbon monoxide alarms

(e) Combination alarms

(f) Various other devices such as linear heat detectors, beam detectors, aspirating detection systems and various other systems, although all of these are typically not suitable for ISs.

Further information on such technologies can be found in publications such as by Warmack et al.[57] All the technologies discussed below are continually evolving, and specifications vary between suppliers. Hence, certain challenges listed below may not apply to all devices as advancements occur. Various technologies have already been rolled out by different organisations and companies in ISs, and it is important to understand how each one functions.

Ionisation smoke alarms work using a radioactive isotope that produces alpha particles, and they detect when smoke particles enter the device. The alpha particles react with air molecules to produce ions that influence a circuit, thereby identifying the presence of the particles. These devices are good for detecting flaming fires, and typically detect smaller particles. However, they are also sensitive to water droplets, dust and other aerosols. Hence, they can experience many false alarms.

Photo-electric smoke alarms use a light source to detect the presence of smoke. When smoke enters the alarm chamber it causes the light source to be scattered, resulting in the smoke particles being detected. They are generally slightly slower at reacting to flaming fires than ionisation alarms, but have fewer nuisance alarms as they are not as affected by small aerosols. However, they respond faster to smouldering fires than ionisation alarms, and are typically a good option when smouldering fires and life safety is a primary concern.

A project undertaken by the Western Cape Government has seen the installation of thousands of smoke alarms in informal settlements, with one pilot site, Wallacedene TRA being monitored for the period of approximately one year.[23] In the case study lives were saved by the smoke alarms and there appears to have been a general increase in awareness regarding fire safety. However, the aforementioned study found that false alarms occurred due to: smoke and steam generated during cooking, especially when oily foods burned; people smoking; steam from baths; burning of traditional herbs (a traditional custom sometimes used for communicating with the ancestors); hairdryers singeing artificial hair; and smoke from small fires used inside for heating (*mbawula*). Alarms placed in smaller homes, near the cooking area or towards the top of sloping roofs experienced more nuisance alarms. Furthermore, insect infestations caused various alarms to malfunction or experience nuisance alarms. Figure 6-9 shows research being conducted to look at how to keep insects from getting into such devices, to reduce the number of false alarms. Based on the discussions above it must be understood that detectors in ISs are often subjected to more insects, smoke and dust/dirt than they would typically be designed for.

Figure 6-9: (Left) Example of an ionisation smoke alarm, (Middle) Example of a photoelectric smoke alarm with a hush button that was used in a project, but experienced problems probably due to bug infestation (the small brown marks on the device are insect faeces), and (Right) ongoing testing through investigating how to prevent insects from getting into devices by installing items such as a steel mesh.

Rate-of-rise alarms rely on detecting a specific minimum change in temperature with time. They can also have thresholds set for certain fixed temperatures at which alarms activate. The benefit of this technology is that they are not highly susceptible to false alarms, and typically a real fire is required to set them off. Conversely, they do not detect smouldering fires as the temperature rise at roof level for a smouldering fire can be as low as 2°C before lethal concentrations of combustion products are present. Also, depending on their location, the size of a dwelling and the rate of fire development they may only give inhabitants a very short period of time to escape before flashover occurs. In previous experiments it has been found that there may be as little as one minute between ignition and flashover in small IS dwellings,[47] although this will vary significantly depending on what is ignited, and where it is. Thousands of rate-of rise alarms have been installed in informal settlements in South Africa with a detector mesh network which enables constant checks of the health of the system and in the event of fire, text-message warnings are sent to members of the affected community. While these detectors are not as effective at protecting life safety for occupants in the dwelling of fire origin, they can provide an early warning to the surrounding community and therefore enable a fast and effective response – i.e. evacuation, community firefighting, and notification to FD, thereby limiting fire spread.

Carbon monoxide (CO) alarms measure CO concentrations in the air and activate at certain thresholds, typically associated with levels that are becoming dangerous. Device sensitivity ranges. Anecdotal feedback in South Africa suggested some devices used have been too sensitive and experienced false alarms. Conversely, testing conducted be Colclough[58] showed that a specific residential CO device tested was very insensitive (did not activate) to both smouldering and flaming fires, but also experienced no nuisance alarms when tested.

Combination alarms use a variety of the technologies listed above, along with others, and combine them to produce a robust signal that typically can have sufficient sensitivity without experiencing as many nuisance alarms. A challenge with such devices is that they are typically more expensive. In the author's opinion such devices may be a long-term solution for informal settlements if the correct technologies can be combined in a cost-effective but robust manner. Unfortunately this is not viable until prices decrease.

Early detection is very important for reducing the number of fire incidents that occur. Warning devices can allow communities to fight fires before they become a problem. Every detector technology has strengths and weaknesses.

6.4 Passive Fire Protection Interventions

6.4.1 Reblocking / area reconfiguration

As introduced previously, reblocking of ISs is occurring. This involves the spatial reconfiguration of settlements and is done in conjunction with residents and NGOs.[59] Some cities have produced proactive reblocking documents and strategies.[60] It has been identified that settlement planning and design affect fire spread, evacuation and firefighting.[61] Access roads and fire breaks will significantly enhance fire department response, promote safe evacuation and reduce the rate at which fires spread. Additional research is required to understand the long-term sustainability of reblocked areas, and how they may change/densify with time. Figure 6-10 shows an example of how the Mshini Wam informal settlement was reblocked in 2013.

Figure 6-10: Re-blocking of the Mshimi Wam informal settlement before (left) and after (right) a re-blocking process [9]

Challenges exist to reblocking efforts, and these will vary from settlement to settlement. Firstly, there is a cost implication, and municipalities and/or NGOs and/or residents will be required to contribute financially. Then, once pathways are created between dwellings it is possible that residents will extend their homes into them, especially as families grow in size, or when members from other areas come to stay with them.[62] The reallocation of space to residents is a challenge as the provision of access ways may require extra space, and residents may not want to give up valuable land area. During the reblocking process inhabitants must be temporarily rehoused. This can be done with other families in the same settlement, or may require off-site housing. In some settlements, such as Imizamo Yethu in Hout Bay, it appears that the presence of "landlords" can make reblocking more difficult.[45] Landlords sometimes have multiple homes, which they rent out, hence the amount of rentable space they have is paramount. This means that they will be unlikely to accept a smaller plot, even if it results in a safer area with improved layouts.

Reblocking also requires an intensive participatory planning process, including extensive community engagement, and service/infrastructure delivery by public utility providers (e.g. Eskom) and government agencies. The reblocking process can therefore take many months, if not years, and the timing is highly dependent on factors such as the level of community social cohesion and buy-in, and coordination of key stakeholders. Due to the amount of effort and time required, reblocking is not yet considered a scalable approach that could benefit a significant portion of people living in informal settlements across South Africa. However, where reblocking projects are carried out, significant fire safety benefits are possible.

It has been investigated whether reblocking can occur immediately after a fire disaster. This is typically not possible as many residents rebuild their homes very quickly (within 1-3 days), meaning that infrastructure cannot be installed in time. Designing and facilitating a reblocking process is a time-consuming process, not suitable for immediately after a disaster has occurred. Also, it is hypothesised that if a community knew that they would receive an upgraded area if a fire occurred, that could incentive dwellers to cause such a fire. Potentially if streamlined processes were developed alongside regular community interaction it would be more feasible to implement reblocking soon after fire events.

Reblocking provides an improved community layout, allowing for better access, evacuation and firefighting activities. However, various challenges exist with this process that need to be addressed.

6.4.2 Fire walls / Fire breaks

Fire walls are an important component of fire safety engineering. By keeping a fire within a single compartment, referred to as compartmentation, the amount of damage caused by a fire is significantly reduced. It may be possible to construct a fire wall through a settlement to create a permanent barrier, thereby limiting the spread. Some organisations have proposed providing increased fire resistance to a line, or lines, of homes to try to compartmentalise a settlement. There are various challenges associated with such initiatives. Fire brands, or flaming embers (See Section 3.1.2), can easily be carried over walls, especially lower ones, meaning that a fire can still spread past a barrier. Physical barriers inhibit evacuation and may lead to larger numbers of fatalities. It should be understood that the number of IS fatalities in large fires, relative to the number of inhabitants affected, is relatively low. It is hypothesised that this is primarily because people can easily evacuate, whereas when more barriers are present people may become more commonly trapped. Also, it remains to be seen whether after a wall has been built if residents will build their homes up against it (to obtain a free, well insulated wall). This may lead to settlement densification along the wall. Furthermore, it may be possible that residents will resist the installation of a wall in a community due to issues such as the settlement requiring reconfiguration, unintended social consequences, cascading impacts to other hazards (e.g. flooding), perceptions that the finances could be better spent elsewhere, etc.

Fire breaks, or fuel reduction zones, are open areas with reduced combustible material and are provided to reduce the chance for a fire crossing them. Fire breaks can prevent and reduce fire spread, whilst also improving access. Hence, permanent infrastructure such as roads or pathways can be used for this purpose. However, it must be appreciated that fires can still cross breaks, especially when strong winds are blowing. Flaming brands can be carried many kilometres and ignite items where they land.[63] Also, during a large fire event residents carry their belongings out to perceived safer areas. This leads to areas which were once clear of fuel becoming fire paths, filled with highly combustible material, as shown in Figure 6-11. Fire breaks around the perimeter of a settlement at interfaces with wildland areas (veld), are beneficial for reducing fire spread from the wildland into the settlement, and vice versa. Fuel breaks in wildland areas require ongoing maintenance, and new homes may be built into them.

Figure 6-11: Residents evacuating, or standing watching, during the 2017 Imizamo Yethu fire. Note the presence of possessions stacked up in the area potentially creating a fuel bridge over a fire break. (Image used permission of Bruce Sutherland, City of Cape Town)

The provision of fire walls may assist with reducing fire spread, but has challenges associated with evacuation, and general practical issues. Providing fuel breaks around the edge of a settlement may reduce fire spread into, or out of, settlements. Permanent infrastructure can be used as fire breaks.

6.4.3 Improved construction materials for homes / Retrofitting of existing homes with fire resistant products (boards, paints, etc.)

In recent years many companies have proposed the use of improved construction materials for new homes. For new formal homes national building regulations should be adhered to (e.g. SANS 10400), and guide which products can be utilised. Guidance from recognised certification organisations, such as Agrément, can also be considered.

When retrofitting homes many options are available, as discussed below. For all the products considered it is important to understand how fire spreads, as presented in Section 3.1.2, as fire spread mechanisms may negate the influence of products. It appears that in most cases fire spreads either by radiation or flame impingement. To protect a home against radiation there should be as few exposed combustible items as possible. Flame impingement has the same requirement, except flames can also enter through openings and ignite items on the other side. Hence, walls with any locations susceptible to ignition (which are common in structures built with poor quality materials and limited tools), may result in a fire starting and spreading within a new dwelling. A high quality fire resistant product may be ineffective if there are gaps around it, as the gaps allow flames to ignite curtains, combustible cladding or any other items within a home. In all homes, including formal homes, openings such as doors and windows can provide weak points through which fire can spread. Residents should be encouraged to close doors and windows when evacuating. *For informal homes, it may be more beneficial to first focus on sealing up holes with non-combustible materials rather than starting with new products on the walls.*

- *Intumescent Paints*

Intumescent paints are activated by heat and swell to thicknesses of between 15 and 40 times their original thickness. They typically consist of components that thermally degrade at certain temperatures, and release gases to cause the expansion of the paint layer.[64] Such paints are commonly used in the construction of steel buildings and have been extensively tested. There has been very limited testing in "real" informal settlement environments accompanying the roll-out of such products in settlements. The authors have seen pictures of homes with paints applied to them which have burnt down. There are many challenges associated with the use of intumescent paints, namely:

(a) As introduced above, paints may not prevent fire spread if there are many openings in poorly built and sealed walls (or through doors and windows), which allow flames to cause ignition.

(b) Surface preparation is very important. If steel surfaces are not properly prepared it may cause the intumescent paint to simply peel off. Many products require that surfaces be sand-blasted or wire-brushed before the application of the paint, which is expensive and time-consuming.

(c) Many products are susceptible to UV and ageing processes, such that they may not last long, especially when placed on the outside. Some paints are highly susceptible to moisture, meaning that in cold, wet winters (such as in Cape Town) their effectiveness will be hindered.

(d) The chemical reaction that causes intumescent paints to expand can occur at temperatures of around 200 to 400°C. At such temperatures it is possible that readily ignitable products (e.g. cardboard) on the back of a thin corrugated iron (steel) sheet may already have ignited.

(e) Paints are typically quite expensive, in terms of cost per m^2 covered. Hence, they may often not be economically feasible, even if the practical issues above can be addressed.

(f) Paints are often not suitable for non-metallic surfaces, such as wood or plastics.

The use of intumescent paint for improving fire safety in ISs is yet to be proven and has significant challenges.

- ***Boarding systems***

Various boarding systems are available for providing fire resistance to formal homes. These include gypsum boards, calcium silicate, vermiculite, magnesium oxide (which must be verified to determine if it contains chlorine, otherwise hydrochloric gas can be released during fires), and various others. Many of these have been extensively tested and are suitable for fire walls. Typically, the weakness of these systems is their joints and installation, which must be carefully attended to. If joints can open up the resistance of boards is negated.

Boarding systems are susceptible to similar challenges as per paint products above, in that for IS dwellings any gaps around boards may make them ineffective. Hence, the installation of boards should be accompanied by the sealing of all openings with fire-resistant products. Boards can be relatively expensive. Some are sensitive to water and may become damaged with time. Board systems also require skilled labour for installation. The cutting, fixing in place, connection and sealing of boards may require skills and tools most IS inhabitants don't have. It is important to correctly fix boards in place, otherwise, they can fall off, or crack, when subjected to fire. Also, boards must be fixed to a flat surface, and are better for regular geometries. Unusual shapes, curved walls and irregular corners are difficult to protect using boarding systems.

- ***Spray-on products***

Various spray applied products are available, such as vermiculite. These have been used in formal construction for many decades. Their application in ISs is relatively new and needs further testing. The benefit of spray applied fire resistant products is that they can take any shape, and are better at sealing openings. However, concerns that should be considered are: (a) does the product adhere to the substrate or must the substrate be prepared before application (e.g. by sand-blasting), (b) has durability of products for UV, ageing, moisture and similar factors been tested, (c) does the product release any toxic fumes when heated or in general usage, and (d) are there large holes on dwellings that would negate the influence of the product even if correctly applied?

- ***Installation of products where fire safety is not the primary objective***

It must be acknowledged that many construction products are installed for reasons such as increased thermal or acoustic insulation, and fire resistance is not the primary objective. In such instances, it should be evaluated whether the product will influence fire safety. If the product is non-combustible it is unlikely to influence fire safety, unless it releases toxic fumes at elevated temperatures. If the product is combustible it may reduce the amount of time inhabitants have to evacuate and increase the rate of fire spread. As an example, some companies have tested a spray applied polyurethane (i.e. foam) to insulate houses. Such products are often highly flammable, can release noxious fumes, and are a potential hazard.

Specialist assistance should be sought from qualified fire engineers to assist in the evaluation of products which may be flammable or produce fumes. However, to quickly determine if decision-makers should bring in fire engineers to evaluate products a small sample of the product could be tested in a fire/braai and its performance noted. If the product rapidly burns away, and/or releases noxious fumes, the product is unlikely to be suitable and may not necessarily need to be considered further. If the performance appears to be acceptable fire engineers should be consulted for further validation. Any preliminary testing should be done in a safe manner with suitable fire safety equipment present, and preferably done in conjunction with the local fire department.

Non-combustible construction systems will promote reduced fire spread rates. However, poor installation and openings can negate the effect of even a high quality product. Openings in dwellings should be sealed with non-combustible items before focussing on protecting walls.

- *Galvanised steel sheeting / Zinc / New corrugated steel sheeting*

In various settlements it has been encountered that residents, NGOs and other organisations have asked if new shiny corrugated iron (i.e. galvanised steel sheeting), often referred as zinc, has a better fire resistance than old, rusted sheeting. The presence of a shiny galvanised layer will decrease the emissivity of sheet (which affects the amount of energy absorbed), meaning that the sheeting will heat up more slowly, but not significantly for such thin steel. After around 400°C the galvanising will melt and run down, as shown in Figure 6-12. Since homes are normally ignited by flame spread through openings, or radiation onto combustible items, the presence of the galvanising will have a negligible impact. If homes were to be ignited through cladding materials spontaneously igniting from heat conducted through steel sheeting, this would be delayed by much less than a minute for a standard fire exposure. Hence, galvanising will result in the sheeting heating up more slowly (but less than a minute in most cases), but dwellings built from new "zinc" should not be regarded as having an improved fire rating.

Figure 6-12: Example of an informal dwelling during a fire, with the galvanising (zinc) melting and starting to run down the side (occurring at position of green-yellow colour). Galvanised sheeting heats up only marginally slower than normal sheeting, and should not be regarded as fire-rated.

Unfortunately, new corrugated iron (galvanised steel) sheeting does not have an improved fire rating relative to normal steel sheeting.

6.4.4 Considering double storey dwellings

A worrying trend emerging in denser settlements is the presence of double storey informal dwellings. Although this solution is good for providing additional living space for residents, it has major safety implications. Recent full-scale tests conducted on a double storey dwelling, as shown in Figure 6-13, have highlighted some important considerations:

- The required safety distance between dwellings to prevent spread increases as more heat is emitted from a burning double storey dwelling.
- It is very difficult for firefighters to suppress fires on the top floor as they cannot see what is burning, and cannot easily direct their water onto it.
- If someone is trapped and must be rescued it is very dangerous to go into a double storey building before, during or after a fire as they are often structurally unsafe.

- These dwellings can collapse on people or adjacent structures.
- The amount of fuel that can burn, and people that must evacuate, increases.
- Collapsing these dwellings is very difficult if a fire break must be made or a structure has burnt out, but is still standing and must be demolished.

Figure 6-13: Full-scale fire test on a double storey dwelling showing the intensity of the fire

6.4.5 Provision of escape from homes

As introduced in Chapter 2, IS homes are often equipped with burglar bars and security gates due to the high prevalence of crime in areas. Residents acknowledge that these will prevent escape if a fire broke out, but they cannot compromise on family security. If residents wake up once a room has filled with smoke they may not be able to find security gate keys before succumbing to the smoke, or before the fire can develop further. Firefighters have reported finding the remains of deceased fire victims trying to unsuccessfully force their children out through burglar bars. To address this issue of escape, some residents have weakened panels in their homes that they can break out in case of emergency, allowing them an alternative escape route. Such techniques could be implemented relatively easily. However, they should not compromise the structural stability of the dwelling. Also, if criminals are aware that homes have weakened panels they may exploit them to break into homes.

The provision of weakened panels can provide an alternative escape route for residents. However, this may compromise security.

6.4.6 Building code application and enforcement

Codes of practice for home construction, fire safety, municipal infrastructure and other formal settlement requirements exist in South Africa. Detailed information regarding fire safety is provided in the application of the National Building Regulations as detailed in SANS 10400-T[36]. Wherever possible, the attainment of such standards should be the long-term objective of informal settlement upgrading. They should certainly be enforced in the manufacture and provision of products such as paraffin stoves (SANS 1906) and electrical items.

However, the enforcement of national construction standards in the interim is typically not possible, as settlements are inherently defined by their lack of code application. There is not a code of practice suitable for such areas, nor should we seek to develop one. The provision of such an IS code would work in opposition to existing national standards, as it would imply that ISs are complaint, and suitable for residents. For further discussion on this topic refer to Section 3.2.

6.5 Fire prevention/Risk of Ignition Interventions/Preparedness

The following section addresses issues associated with fire prevention, reducing the risk of ignition and community preparedness. Many aspects covered below overlap with aspects addressed above (e.g. good fire safety preparations may result in smoke alarms being provided and hydrant maintenance occurring). Money spent on disaster mitigation usually results in significant savings in future disaster costs, with estimates ranging between $4 and $10 in savings for every $1 spent on mitigation. Hence, preparedness and risk mitigation should be a key component of all fire safety strategies. However, disaster preparedness requires ongoing work and needs financing which often cannot easily show “concrete” results from a political point of view (as opposed to a new fire truck being handed over by a politician).

From a risk of ignition perspective a serious challenge with IS fire safety is that people often rely on multiple cheap and hazardous sources of light and heat such as candles paraffin stoves, electrical connections of wide variety and hearth fires.[2] Hence, it is important to try to improve fire safety by reducing the risk of ignition.

6.5.1 Mapping of areas to analyse risk

An important aspect of responding to disasters is preparedness. Municipalities, NGOs, fire departments and other organisations working in communities should have maps showing important fire safety aspects. These include:

- Location of the nearest fire station, police department and medical facilities.
- Location of running water sources
- Location of hydrants such that they can be protected, maintained and utilised
- Number of people and homes in different areas, along with the density of the settlement in different areas
- For fire departments: (a) Access routes into communities, and how different parts of a settlement should be reached. (b) Identification of high risk areas based on density, the number of previous fire incidents, demographics (e.g. young, single males are often a higher risk profile), difficulty in accessing fires due to road access, identification of previous attacks on firefighters and communities hostile to firefighters, etc.

Fire safety maps are relatively easy to produce (e.g. using free software such as Google Earth) and can assist organisations in understanding and mapping risk factors and response efforts.

6.5.2 Electrification

Electrification is often critical in improving people's quality of life. It allows us to buy modern appliances, such as kettles, stoves, microwaves, fridges, televisions and sound systems. These improve people's leisure options and allow more time for leisure by speeding up once time-consuming chores. It also has health benefits. The shift from paraffin to electricity improves the air quality in dwellings, while fridges allow households to buy and store fresh food, encouraging healthier diets and reducing foodborne illnesses. Electric lighting also allows students to read and study at night and children returning from school can safely warm left-over food in microwaves rather than lighting paraffin stoves using matches. Electricity supply also stimulates many new businesses and home industries.

Many homes in South Africa do not have access to electricity, which can be linked to challenges regarding inhabitants not having legal tenure. However, even when electricity is provided it does not guarantee that residents transition entirely to electrical appliances or up the energy ladder. A study by Francioli[62] has showed that in various settlements studied 67.2% of residents employed "energy stacking", which involves the use of both electrical and non-electrical energy sources (especially paraffin for cooking). Similar trends have been identified by other authors.[65]

The formal electrification of settlements should be encouraged, as electricity is important for improving standards of living. Various sources have identified it as a primary way of reducing the use of hazardous fuel sources.[66,67] However, challenges associated with the provision of electricity should be understood. These include the fact that inhabitants may overload circuits, or use old electrical appliances, leading to electrical fires. Figure 6-14 is an example showing many electrical cables that are run from local electrical infrastructure leading to the presence of dangerous, low-hanging wires that can cause electrocution or fires. These wires also obstruct fire truck access. It can be difficult installing metered electrical connections in many homes (due to access, infrastructure requirements, locating specific dwellings, poor construction materials, etc.), and replacing these after a fire is a significant expense.

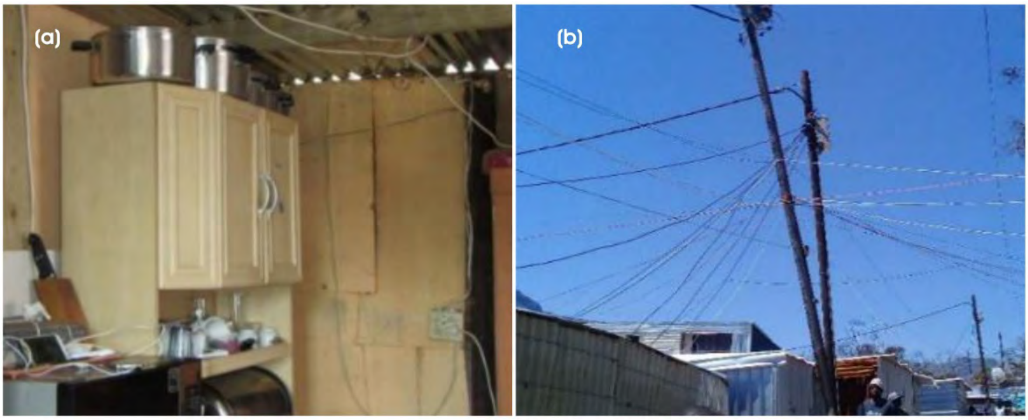

Figure 6-14: (a) View inside a home with overloaded plugs (on the far left side), hanging wires (top) and wires easily accessible to children (right). (b) Formal electrical lines (top) and numerous informal connections (middle and bottom) running dangerously through an informal settlement. [9]

Electrification is important, should be encouraged and does reduce fire risk, but does not eliminate it. Informal electrical connections, and incorrect electrical usage, are a problem.

6.5.3 Improved cooking, lighting and heating interventions

A wide variety of improved cooking, lighting and space heating interventions have been developed by individuals and companies across the world. Some of these include solar systems[68], improved candle usage systems[69], safer cooking stoves[70,71] including improved paraffin stoves[72], amongst many other innovations. Undoubtedly the use of unsafe cook stoves is a major problem, and an independent report on the testing of South African stoves found that all nine locally available stove models investigated resulted in a rapidly spreading fire when knocked over, due to fuel being spilt.[72] Some general considerations regarding the many options available are:

- Improved safe lighting, space heating or cooking appliances will promote improved fire safety.
- Devices issued free of charge to a community may be sold if they have resale value.
- Devices should have minimal ongoing running costs, e.g. special fuel to be used in cook stoves that must be bought, or 9V batteries for electrical items. The authors have visited homes where 9V batteries from smoke alarms have been put into TV remotes, resulting in the smoke alarm being ineffective.
- Items should be very robust as they may not be cared for properly.
- Many SABS codes of practice exist for the manufacturing of products (e.g. cooking stoves), and it should be ensured that these are being enforced, such that poor quality, unsafe appliances are not being sold.
- Paraffin must be sold in bottles with a safety cap, and the use of cool drink or milk bottles must be prohibited.

6.5.4 Fire safety kits

Various organisations and municipalities have developed kits to assist residents with improving fire safety. As an example, the City of Johannesburg has issued the Jozi Safety Kit containing a para-safe stove, a hydro-gel and bandage to treat minor burns, solar lantern light, paraffin container with a safety cap, smoke detector, fire retardant spray and a bucket to store water.[73] The City of Johannesburg claims to have seen a 50% reduction in the number of fires since the inception of the Jozi Safety Kits in the 2008/9 financial year.[74]

The provision of fire safety items to community members will invariably help improve fire safety and reduce risk, and this should be encouraged. Challenges to the provision of kits include the cost of kits, the need for training of people to use contents (e.g. burn treatment), the possibility that people will not install items such as smoke alarms, and the reality that contents may be sold. Also, contents included in the kits should be carefully verified to ensure that they meet required safety standards. In transient communities, such kits would need to be issued at regular intervals (e.g. every few years).

A well-planned fire safety kit can provide many important items to community members. Kits can become expensive and need to be issued at regular intervals.

6.5.5 Disaster relief kits

After a fire incident many municipalities in South Africa issue disaster relief kits to provide community members with materials needed to rebuild homes. There has been much discussion regarding the issuing of housing kits, and what should be contained in them. In most cases, the rebuilt homes have the same, or possibly worse, fire risk as the homes that they replace. Anecdotally it has been suggested that if kits are very generous, people may be incentivised to burn their own houses down to receive the kits.

As an example of a disaster relief kit, the list below is for an “enhanced emergency housing kit” supplied by the City of Cape Town:[75]

- 5 No. 76mm x 76mm x 2.7m SA Pine poles
- 9 No. 76mm x 50mm x 3.0m SA Pine poles
- 5 No. 3.3m x 610mm (cover) galvanised corrugated steel roof sheets of 0.5 mm thickness
- 20 No. 2.4m x 610mm (cover) galvanised corrugated steel roof sheets of 0.5 mm thickness
- 1 No. wooden batten door with 2 x 150mm T hinges and a lockset/padlock
- 1 No. 600mm x 600mm wooden window glazed with 4mm glass (window must be able to open)
- 1 kg 100mm wire nails
- 1 kg 75mm wire nails
- 1 kg 32mm clout nails.
- To prevent further fires, or to delay the spread of fires, all wooden material (poles, door, and window), shall be painted with an approved fire retardant paint prior to delivery.

Disaster relief kits help community members rebuild after their homes are destroyed in a fire. However, post-fire safety risks remain the same as homes are typically not improved.

6.5.6 Education campaigns

Education has an important influence on all aspects of fire safety. A person with good training is (a) more likely to have safer practices, reducing the chance of fires starting, (b) understands how to correctly and safely suppress a fire, (c) knows what to do to try reduce fire spread or how to produce homes with improved fire safety, and (d) knows how to safely escape from a fire including how to provide assistance to others (a critical role for teachers leading the evacuation of several children, for example). However, education and training does not necessarily lead to changes in the way people behave, as people can forget/ignore/misunderstand what they have been taught, and may not have the resources to implement what they know should be done (e.g. buying better quality cook stoves). Fire departments, municipalities, NGOs and schools all need ongoing and active fire safety campaigns.

Educational efforts at all levels can assist in improving fire safety.

6.5.7 Medical training for burn treatment

It is important that local communities know how to contact the local medical services, where their nearest clinic/hospital is and how to treat burn wounds. Refer to Annex B regarding details about basic first aid for burn wounds.

6.5.8 Fire insurance

An important component of disaster relief following large fires in formal areas is insurance cover. This helps spread risk and provide support during times of need. The provision of finance from insurance policies soon after an event assists recovery efforts and means that the state, NGOs and local residents do not have to provide all the support. Recently a number of organisations have developed insurance products for ISs.[76,77] These products focus on providing low-cost policies that provide protection for buildings (including IS dwellings) and household contents. The companies have contracts outlining what specific events are covered, and can provide rapid finance to insured persons after an event. Community members may also create forms of risk sharing through different means (e.g. 'stokvels') where groups of people may assist each other, sometimes in exchange for policies or invested amounts.

Insurance and the spreading of financial risk is beneficial for assisting with post-fire recovery. However, inhabitants may not have the finances required to pay for insurance, or may have higher priorities. Furthermore, due to many community members' unfamiliarity with insurance policies, and language barriers, they may be exploited if formal financial controls and sound policies are not in place.

Insurance policies help spread risk and assist with disaster recovery. Care should be taken to ensure that inhabitants understand policies and are not exploited.

6.6 Summary

From the discussions above it can be seen that an extensive number of different interventions, strategies and products can be used to improve fire safety, and discussions in this chapter should not be seen as comprehensive as many other products exist. However, the challenge is typically that only a limited budget is available so inhabitants, NGOs, community-based organisations and municipalities should seek "low hanging fruit" which can result in large improvements relative to the cost of the intervention. There is no perfect intervention or mix of interventions, but Chapter 8 will discuss various options for trying to optimise the response to fires.

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7. *Fire safety for backyard dwellings in formal housing areas*

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This chapter focusses on fire safety for backyard dwellings constructed in formal housing areas. These dwellings are also referred by names such as shacks-in-the-back, backyarding, informal rental, ancillary units, secondary or subsequent dwellings, and even slums. Such homes were introduced in Section 2.4, and in many respects the issues of fire safety discussed throughout this work directly apply to such homes. However, there are distinct differences which are addressed in this chapter and should be appreciated when developing fire safety strategies.

A challenge with improving safety for backyard dwellings is that minimal fire engineering research has focussed on them, making definitive statements difficult. Furthermore, the distinction between formal dwellings, informal dwellings and backyard dwellings becomes increasingly blurred as areas progressively densify. In some areas the number of backyard dwellings outnumbers the formal dwellings, meaning that such areas resemble an informal settlement more than a formal settlement. Figure 7-1 shows a backyard dwelling alongside a formal structure (in addition to a large amount of flammable material), along with an aerial view of the Masiphumelele area where various formal, informal and backyard dwellings occur. In the latter image it can be seen how the different dwelling types merge into each other.

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Figure 7-1: Images from Masiphumelele, Cape Town: (Top) Backyard dwelling adjacent to a formal dwelling, also depicting a high fuel load. (Bottom) Aerial view showing formal dwellings, many of which have backyard dwellings, along with a dense informal settlement (upper side of image).[78]

7.1 The backyard dwelling context

Backyarding in South Africa has been identified as a "a multi-billion Rand accommodation and economic sub-sector that provides accommodation options to many low-income households unwilling to, or unable to procure subsidised or formal privately developed bonded housing."[79] The number of households living in backyard dwellings increased from 460,000 in 2001 to 713,000 in 2011 according to the national census, showing an increase of 55%.[22] Based on such growth rates it is inevitable that the number of backyard dwellings will increase further in the coming years. However, Zweig notes that "proliferation of backyard dwellings is contributing to an increasingly risk-prone environment posing a critical development challenge in terms of infrastructural need and service provision."[80]

Various South African studies have highlighted how people residing in backyard dwellings are often marginalised, have limited access to facilities, may be exploited by their landlord, and experience poor living conditions.[80] Lemanski states that backyarders "lack the mass visibility and collective force of an informal settlement, being instead merged into existing residential areas and functioning alongside neighbours with formal tenure rights and access to infrastructure and services."[81]

Formal home owners may construct informal dwellings in their backyards to house family members (immediate or more distantly related) or friends, or to obtain rental income. Services such as water, electricity, refuse removal and sanitation may be provided by the landlord. Few formal contracts exist between tenants and landlords. Many backyard dwellers fall within the "gap" whereby they earn an income so are unable to obtain free, state-subsidised homes (i.e. earn an income over R3501 pm) but also cannot afford to rent or purchase a formal house.[82] Based on the facts above, backyard dwellers experience multiple challenges compounded but an ambiguous legal standing.

7.2 Fire safety engineering considerations for backyard dwellings

The construction materials used for backyard dwellings vary as widely as those found in ISs. Some backyard dwellings are simply an extension of the formal home, and are constructed from traditional methods such as brickwork. However, in lower income areas homes are typically more flammable than formal homes, and are often built in the same manner as informal homes as discussed in preceding chapters. As per informal dwellings, backyard dwellings often have high fuel loads around them due to materials, furniture, possessions, wood, garbage and other items being stored.

In some areas "Wendy house" type backyard dwellings are common. These are wooden structures normally purchased to be used as garden sheds or children's playhouses. In many cases the wood has been treated with varnish or oils which may make them even more flammable, and in research in Klapmuts it was found that diesel is even used, whilst openings are filled with newspaper.[83]

Research by Roussouw[84] that focussed on the formal area of Wallacedene has shown that an increase in the number of backyard structures has been associated with an increase in the number of fire incidents. This is linked to both the fact that there are more dwellings plus people in the area (i.e. higher probability of ignition), along with the fact that backyard dwellings typically have a higher fire risk. Fire incident reports from the formal areas of Wallacedene often listed informal structures as having been affected, highlighting that backyard dwellings were involved rather than formal structures. By mapping fire incident reports it may be possible to quantify the number of backyard dwellings affected by identifying informal structures recorded in formal areas, but this remains to be investigated. Currently fire incident reports do not have a standardised way of reporting whether it was a formal house or a backyard dwelling that was affected by a fire, but the inclusion of such data would be useful for quantifying the scale and nature of the issue.

The aforementioned research in Wallacedene also highlighted that electrical faults accounted for almost 50% of the incidents that occurred, although this will vary from area to area. A large study covering four different low-cost housing communities in Cape Town found that electrical connections were a high fire risk for backyard dwellings.[85] The pervasiveness of electrical fire safety is not surprising as power is supplied to residents from formal homes, and this may be done through poor quality electrical installations or extension cords, and electrical connections may become overloaded.[13] Figure 7-2 presents data from the aforementioned Klapmuts study where the prevalence of electrical items in backyard dwellings is provided, showing that most homes have at least a stove, TV, fridge, cellphone charger and lights, but with some even having heaters and computers. "Other" appliances include microwaves, washing machines, hair dryers and sound systems. In most cases backyard dwellers rely on the landlord to supply them with electricity and this is sometimes done at inflated rates. In such cases tenants are more likely to use alternative, but potentially more dangerous, energy sources such as paraffin and candles. Furthermore, anecdotal incidents are reported of landlords not supplying power due to payment disputes or if the landlord has not purchased more electricity for the prepaid systems commonly employed.

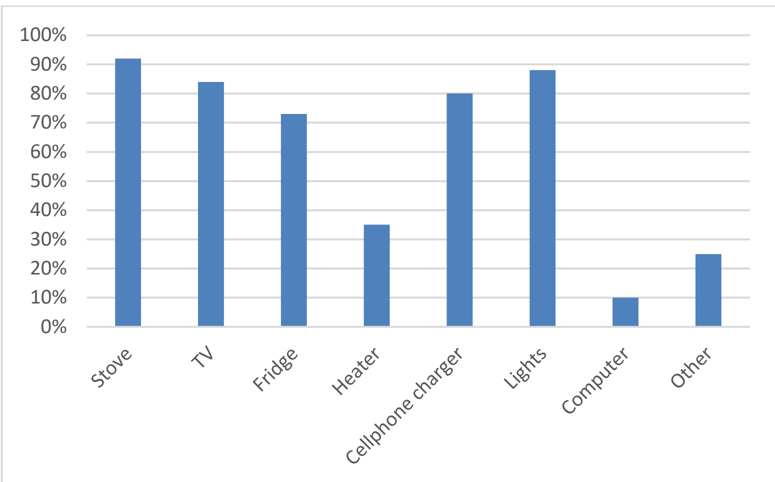

Figure 7-2: Prevalence of electrical appliances in backyard dwellings in Klapmuts (based on [83])

The primary differences that affect fire safety in backyard structures can be summarised as follows, with a number of these aspects illustrated in Figure 7-3:

- The presence of formal structures, walls and roads often limits the physical size of such fires so they do not affect as many homes in a single incident as in informal settlements.

- Evacuation is more difficult. Formal homes, walls and other structures block escape. Hence, the chance of fatal incidents occurring is higher per fire event in comparison to IS fires. This needs to be proven through further research but appears to be the case from anecdotal feedback and the limited information currently available.

- Electrical fires are common as each formal house will have an electrical supply, and in most cases power is supplied to backyard structures.

- After a fire backyard dwellers will typically not receive a relief kit/starter pack (see Section 6.5.5) as they are not recognised in the same manner.

- There is less social cohesion and cooperation than found in ISs. In ISs community members will often fight fires together out of a common interest in saving homes. Anecdotal incidents have highlighted that residents in the immediate vicinity of a burning backyard dwelling may assist in firefighting efforts, as the fire could spread to their homes, but the total number of people assisting is likely to be less.

- Due to backyard dwellings often being hidden behind formal homes, fences, walls and other barriers fires may go unnoticed for longer. Hence, there is less time to save trapped or incapacitated inhabitants, alert the fire department and intervene to suppress such fires.

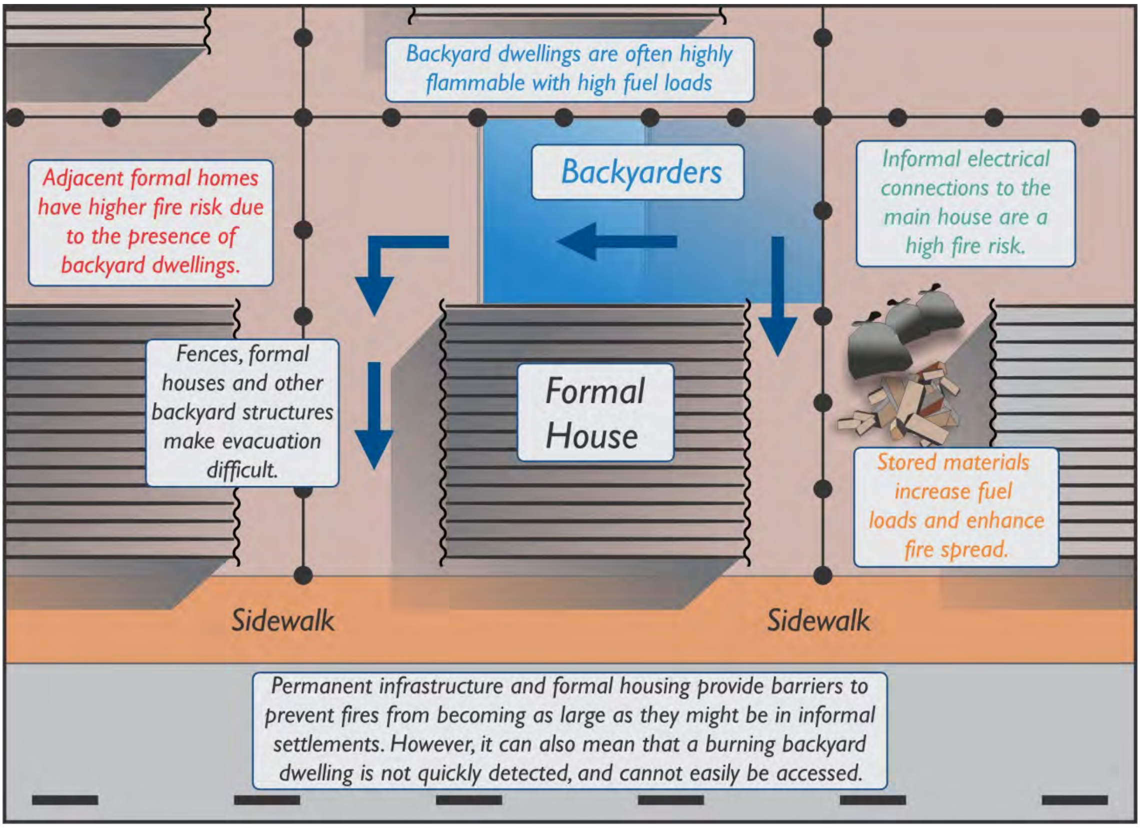

Figure 7-3: Factors affecting fire safety of backyard dwellings (Graphic design by DTP Solutions)

7.3 Strategies for backyard dwellings

If backyard dwellings are present in an area and fire safety strategies are being developed to address them then the following are specific aspects that can be considered, in addition to those discussed in preceding chapters:

- Early detection is even more important for backyard dwellings than in ISs due to challenges regarding fires being detected, evacuation being hindered, difficult fire department access and reduced support from neighbours. Hence, the supply of detectors should feature more prominently as early warning may be the only way to save inhabitants after a fire has started.

- Where possible, try reduce or limit the number of backyard dwellings constructed adjacent to each formal home. A lower home density will be associated with fewer fire incidents, improved chance of escape, reduced rate of fire spread and smaller total losses.

- Promoting the phone number for the local fire department, as well as building relationships between the fire department and communities, is as important for backyarding communities as it is for IS inhabitants.

- Ongoing mapping of areas should occur for municipalities to identify the number of backyard dwellings in an area such that the municipality can quantify their risk. Such information must be shared between fire departments, municipalities, government departments and similar institutions.

- Municipalities should develop strategies for how backyard dwellers are supported after a fire incident. Due to their ambiguous legal standing they often receive no support, and become even more marginalised after a fire. The following are important considerations and areas for further research and policy development: within a municipality who should be responsible for providing support? What existing projects can support be aligned with? How can such work be implemented so that it can be effective? In a formal bonded house to what extent would insurance cover backyard dwelling losses and the impacts of a fire starting in such a structure? How does the situation of renting/subletting homes from municipalities influence this situation?

- Implement means of improving or controlling electrical supplies to informal homes. This is very difficult to do, but electrical fires do appear to play a prominent role in fire incidents.

- Educational efforts to make inhabitants aware about fire risk, and measures for reducing it, are important. Training regarding planning for evacuation in an incident will be beneficial.

- Try to reduce the amount of material stored between dwellings as this provides a "bridge" that fires can spread across.

- Encourage landlords and tenants to have formal contracts in place which will encourage suitable electricity provision, avoid the provision of electricity at inflated prices, provide details regarding safety and address similar factors. Unfortunately the legal standing of such contracts, and the extent to which they can be enforced, is questionable.

In terms of strategies the following interventions discussed in Chapter 6 are likely to be *less* effective in relation to areas where there are numerous backyard dwellings:

- Interventions requiring widespread social cohesion and cooperation are likely to be problematic, such as community response teams. However, residents in the immediate vicinity of a burning structure may be willing to assist.

- Formal areas typically have fixed infrastructure and property layouts. Hence, it is not possible to do reblocking, place fire breaks or construct any sort of firewalls as considered for ISs. Between individual homes it may be possible to provide firewalls, although it is unclear who would fund this, to what extent they would be effective and whether they may increase the risk of people becoming trapped.

Image used permission of Justin Sullivan

8. Conclusions and the way forward

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As stated in Chapter 1: *the aim of this work is to improve informal settlement fire safety through a holistic understanding of (a) the science of fire behaviour, (b) the application of fire safety engineering, (c) an understanding of the social realities of inhabitants, (d) an acknowledgement of the complexity of addressing the problems in settlements, and (e) a realisation of the limited resources available. We want to know: How can we do as much as possible with the limited resources we have?*

The discussions throughout this work acknowledge that what is being proposed falls short requirements stipulated in fire safety guidelines for formal homes. However, by providing holistic fire safety strategies that provide a level of risk reduction appropriate to the resources available and the expectations of communities, significant progress can be made. Difficult questions such as "how safe is safe enough" and "what level of support could be expected during and after a fire" must be realistically answered. Inhabitants have a range of competing challenges, meaning that fire safety may be lower on their list of priorities than might be expected, especially when providing food, shelter, safety and education for family members consumes a large portion of their efforts and resources. Hence, any intervention and strategy must understand the local challenges experienced by residents and what can be realistically and sustainably implemented. Decision makers should avoid "quick fixes" and rather engage with communities, fire departments, NGOs and all other stakeholders to progressively improve safety. Nevertheless, we, as a society, will pay for the cost of informal settlement incidents. It is simply the question of whether we pay a lower amount through preparation, or a higher amount through response.

Chapter citation: Walls, R. (2020), "8. Conclusions and the way forward", in Walls, R. (Ed.), *Fire Safety Engineering Guideline for Informal Settlements: Towards Practical Solutions for a Complex Problem in South Africa,* FireSUN Publications, Stellenbosch, pp. 121–128.

8.1 A summary - So what interventions should we adopt?

From the discussions in Chapter 6 it can be seen that a wide variety of products, strategies and interventions are available that municipalities, NGOs and communities can adopt. As discussed in Chapter 2, a basket of solutions is typically needed, and a single intervention may have a very limited impact. Throughout the development process of a fire strategy for a community it is important to identify "low-hanging-fruit", which are the interventions that can provide the greatest benefit for relatively low investment. Based on the author of this chapter's point of view (which is influenced by settlements in the Western Cape metropolitan areas) the following actions and interventions seem particularly achievable and accessible (but these will vary from community to community).

- *Community involvement*
    - Always engage with the community in a respectful way, involving them in the process of developing solutions. See discussions in Chapter 2.
    - The simple guidelines for getting communities involved before and during events, as presented in Section 6.2, could be introduced by NGOs or other community-based organisations.
    - Work with the community to keep access routes open for fire trucks before and during events.
    - Develop and train individuals or groups within communities to be responders to fires, to work with the fire department, to give feedback on incidents, notify authorities of damaged infrastructure and similar aspects.
    - It is important to realise that communities have numerous needs, and fire safety is just one of them. It should be investigated how any existing work within informal settlements (such as to promote energy efficiency, improve community health, provide social services, install water or electrical infrastructure, etc.) can be utilised to also improve fire safety in any way. This will require cooperation between different governmental or municipal departments, NGOs and community-based organisations.
- *Active fire protection*
    - Water buckets are generally the most reliable way for communities to carry water from a water point to suppress fires. Community training on bucket brigades and the provision of buckets may assist.

- The provision of water supply points (standpipes) which are regularly maintained and have sufficient pressure is important both for people's health, quality of life and for fire safety.

- Promote the local fire department number regularly and in many ways (until the national unified emergency number is implemented, and then promote that number instead).

- Promote good relationships between the fire department and community members. Various discussions on ways to do this are presented in Section 6.3.1. Training sessions with the community, hosted in or near the community, may be beneficial. However, it must be realised that most fire brigades have limited personnel, and the additional workload should be carefully considered and budgeted for. Potentially budget should be made available for appointing officers whose specific focus is on addressing informal settlement fire safety through community engagement.

- Ensure that fire hydrants are operational and regularly maintained. This is often more difficult than it initially appears.

- Early warning is always beneficial so the installation of detectors is highly beneficial. However, it must be remembered that smoke alarms can often have numerous false alarms, and alarms that rely on a temperature signal will typically not react to a smouldering fire. (See Section 6.3.7). Hence, they require other interventions alongside, and should be followed-up.

    - Note: If smoke/fire alarms are going to be rolled-out, aim to roll-out these in higher risk homes as the first priority. As an example, internationally social workers have become involved in the process, as they are exposed to household vulnerabilities (abuse, alcoholism, child-headed households, etc.) which are commonly associated higher fire risk.

- *Passive fire protection*

    - Numerous construction products are relatively inefficient at preventing fire spread in informal settlements. It must be remembered that a *system* must be fire-rated, and not only a product. Consider all the fire spread mechanisms discussed in Section 3.1.2. Hence, even if a high quality fire board is installed, but it has gaps around it, or an open window next to it, the product will be relatively ineffective. Any product that is used for lining or protecting people's homes should be tested. Often formal fire tests from laboratories are expensive and take time, and most people do not have the training required to interpret the test report. Even basic testing by a local fire brigade will quickly reveal how flammable many products are, especially plastics or foams and those products incorporating polystyrene.

This may highlight that certain products are not suitable, without needing expensive testing. As a note:

- Galvanised steel (zinc) does not have superior fire performance to normal sheeting.
- Intumescent (fire-resistant) paints have numerous challenges associated with them and are unlikely to be effective in informal settlement environments.
- Homes are often lined for other reasons, such as for thermal or acoustic insulation. The behaviour of such products should be considered by competent fire engineers before widespread rollout.

- The closing of openings in homes, and the removal of highly combustible draught stoppers (e.g. newspaper shoved between roofs and sidewalls), can assist in reducing fire spread. The installation of non-combustible materials in these openings is preferable, even if it is clay/mud and cement mix.
- Try to maintain distance between homes. However, this is often very challenging.
- It appears re-blocking has potential, but is not a simple or easy process.

- *Fire prevention / Risk of Ignition Interventions / Preparedness*
  - Carry out mapping exercises to analyse how to access settlements, locate infrastructure, identify higher risk areas and plan for disasters.
  - Electrification will generally assist with lowering fire risk, and should be encouraged. However, it will not eliminate the risk, and informal electrical connections should be kept to a minimum.
  - Various cooking, lighting and heating interventions are available. If sponsors are willing to provide these they could be considered. It must be ensured that products are robust, are cheap to maintain and operate, and have been thoroughly tested.
  - Disaster relief kits are beneficial, but do recreate the same risk after an event.
  - If higher value fire suppression items, such as fire extinguishers, are to be rolled out they should only be placed if they can be kept secure and used by someone who has been trained.

8.2 Trends to consider in the future

Informal settlements will continue to grow at an alarming rate unless there are major economic or social changes. With settlement growth comes settlement densification, and the densest settlements are typically the highest fire risk. Currently, many municipalities with lower populations are experiencing relatively small fires, and not the large fires engulfing hundreds of homes as seen in the larger metros. However, this will change with time, and more and more municipalities will start experiencing larger fires as settlements evolve. This will place further strain on firefighting resources and disaster management budgets. Mitigation and preparedness, rather than only response, is essential for dealing with the problem.

Double storey informal homes, as discussed in Section 6.4.4, are a major concern. With settlement densification, more double story informal homes are expected. Should these become common in settlements it will result in a severe fire risk increase. Fires will spread faster and firefighters will be forced to fight fires from a distance as structural collapse will become a major risk.

8.3 Research needs

From this report, it should be appreciated the science, engineering and disaster management aspects of informal settlement fire safety are by no means solved and fully understood. There are numerous aspects requiring further research. Some of the specific aspects identified in this report include:

- *Interventions*

    - Further testing is required to find low-cost methods for increasing the fire resistance of homes, especially in terms of closing openings, removing combustible draughtstoppers, and simple modifications such as bending roof sheeting over joints.

    - The development of systems to ensure that adequately maintained fire hydrants are available. Vandalism and the usage of hydrants for domestic water are ongoing challenges.

    - Investigate how sustainable re-blocking efforts are, and how this can be successfully implemented. Ongoing research is being done regarding this. Furthermore, it should be determined how fast a fire may spread through a re-blocked area through small-scale testing or computer modelling.

    - Develop a detailed cost-benefit analysis for municipalities for the interventions discussed in this document. It is likely that an approach or methodology will need to be developed before this can be done. Due to large variations in resources, populations, technology availability, fire department capacity and similar factors it is very difficult to present a broad cost-benefit analysis for all municipalities.

- *Training, response and community relationships*

  - An important problem faced when developing fire safety interventions is that data regarding fire cause is often incomplete and may not be accurate. It is very difficult to accurately determine what caused a fire, and then how it spread through a settlement. There is a need to develop better post-fire investigations such that, where possible, fire causes can be identified with more certainty, and additional data can be obtained for incidents that will help improve response, interventions and community engagement methods.

  - Investigate ways of improving relationships between the fire brigade and communities. Multiple options and opportunities are discussed in Section 6.3.1.

  - Develop training facilities and strategies for fire departments, NGOs and community organisations engaging with communities. These could include setups for doing bucket brigade suppression training, putting out oil fires, evacuation planning, fire drills or other aspects. Ideally, these should be portable to be able to be taken to the community. Many such training systems already exist.

  - The fire timeline presented in Chapter 3 highlights the fact that many factors influence the rate at which fires can be responded to and suppressed. Real data from large numbers of callouts should be analysed to determine how to optimise callouts, how many vehicles should be dispatched under standard operating procedures, how to determine what fires (e.g. based on time of day or location) are high risk and require additional resources immediately, and similar disaster management topics.

  - Develop training material for fire brigades that provide insight on fire behaviour in informal settlements.

  - Seek to understand human decision-making, movement and behaviour during fire incidents as such issues are important for responders and for communities. Studies looking at how people evacuate, where they move possessions to, how to better access settlements during incidents, how to improve emergency vehicle movement and similar aspects would assist in our understanding of events, and could inform fire risk assessments, informal settlement upgrading or reblocking projects, service delivery (e.g. road infrastructure) and evacuation planning.

  - Develop small-scale fire tests (i.e. a mini mock settlement) that can be built to simulate fire spread in settlements. These can either be used to train inhabitants or be used by decision-makers when considering different layouts and how these might influence fire spread.

- It is known that many fires are never reported to the fire department because they are managed by the community, and further firefighting support is not needed. Investigate methods of firefighting used by communities and informal training that takes place between community members with regards to fire safety, including fire prevention and response, even though it may not be called fire safety (e.g. mother teaching a child to keep paraffin bottles away from a stove while cooking).

- *Technology*

  - Developing intelligent smoke alarms with modified sensitivity to reduce the number of false alarms that occur. New technologies that incorporate artificial intelligence are being used overseas, and these may become affordable and suitable in coming years for local implementation. For any device, it must be investigated how to ensure that insects cannot cause false alarms.

  - Produce fire spread models for settlements to assist with response and planning. It will be possible in the near future to simulate fire spread through settlements using computer models. Results can be used (a) by firefighters responding to incidents to give them insight on the size event that they might arrive at, (b) by firefighters during large incidents such that they can understand where the fire is moving to, and how fast it is moving for planning additional resources, (c) for municipalities and organisations to identify what size incidents they may have to respond to or plan for, and (d) to identify higher risk areas.

  - Modern firefighter training is adopting virtual reality systems which allows for simulated training in difficult environments. It may be possible to create suitable informal settlement simulations (that include factors such as residents cutting hoses and difficult to locate hydrants), and use these for training firefighters. These will not be perfect, and many real-world factors will be difficult to include, but still may be beneficial.

  - Integrate fire spread models with other sociotechnical fire risk factors, informed by mapping, surveying, community engagement, and engagement with other key stakeholders, to develop an integrated, holistic approach to assess fire risk in an IS, and across many ISs in a city, and streamline the decision making process for community fire strategy development.

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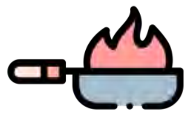
Annex A: Suppressing fires

A.1 ELECTRICAL FIRES

When trying to put out an electrical fire you need to be careful because throwing water onto it may cause electrocution. Hence, there are a couple tips that should be followed:

1. *Turn off* the electricity.
2. **Don't use water** to put it out as you can electrocute yourself.
3. *Baking soda* can be used to suppress small fires. Baking soda contains sodium bicarbonate, which is used in fire extinguishers.
4. Remove the oxygen source. This can be done but smothering the fire through using a thick blanket, or thick clothing. Only do this if the fire is still small and it is safe to do so.
5. Use a fire extinguisher. You will need a *Class C* extinguisher. Many extinguishers are suitable for class A, B, and C.

A.2 OIL FIRES



1. Oil fires can start easily when cooking oil is left on a stove too long and ignites. Put a *metal lid* over the burning oil, or something metal such as a cookie pan or plate. *Turn off* the heat source, e.g. if you are cooking on a stove. **Don't use water** to put it out as the water can become steam when it lands in a burning pot and is heated. The sudden expansion of steam can cause the flaming oil to be thrown all over a room. Also, don't use anything glass as it will shatter, or plastic as it will catch fire.
2. *Baking soda* can be used to suppress small fires.
3. Use a Class B fire extinguisher as a last resort. Many extinguishers are for class suitable for class A, B, and C.
4. Do not try move the pot or pan out of the room. You may spill burning oil onto yourself.
5. A thick blanket, or wet piece of material, can be used but care must be taken as they may ignite.

A.3 WHAT IF I CAN'T PUT THE FIRE OUT?

1. Get out the house as fast as possible and get your family members out.
2. Close the door as you leave to prevent the fire from spreading.
3. Call the fire department as soon as possible.
4. Do not go back to your home.
5. Refer to Section 6.2 for various activities that community members can perform during a fire.

Annex B: Basic first aid for burn wounds

For any burn wound that a person suffers the lists below present a number of important things "To Do" and to "Do Not Do". These are only simplified guidelines and for any serious cases medical care will be required.

TO DO!

- Immediately cool the burn with running water (cold tap) for at least 10 minutes or longer.
- Remove any clothing or jewellery from the area if they are not stuck to the burn.
- Apply vaseline to small, superficial burns (not to broken skin).
- Go to the clinic or hospital if:
  - the burns are bigger than a hand/palm size,
  - or have broken through the skin,
  - or are on the face or neck,
  - or the burnt patient is a child or elderly person or sick person,
  - or if the burns are dirty,
  - or if the burns get worse,
  - or if the person gets sick after the burn.
- Gently clean the burn every day with mild soap and tap water.

DO NOT DO!

- Apply ice to the burn.
- Apply ice cold (fridge) water to the burn.
- Apply butter/oil/toothpaste/milk or other home remedies to the burn.
- Pop blisters.
- Put a dry bandage over an open burn wound.
- Scrub a burn wound.
- Put a tight (constricting) bandage over a burn.

Every day across South Africa homes are burning down in informal settlements. Some people are injured. Others lose everything they own. Some die. Fire brigades, NGOs, municipalities, governmental organisations and many other groups are working hard to develop solutions to improve fire safety. However, with the complex nature of fire, and the complex nature of informal settlement societies, many interventions have been unsuccessful, or have been incorrectly implemented.

The ideal situation would be to alleviate informal settlements by providing people with safer code-compliant homes. However, in reality demand exceeds supply, resources remain limited, and populations are growing. Given the dire reality, we need to improve circumstances where possible. Hence, this work aims to improve informal settlement fire safety through a holistic understanding of: (a) the science of fire behaviour, (b) the application of fire safety engineering, (c) an understanding of the social realities of inhabitants, (d) an acknowledgement of the complexity of addressing the problems in settlements, and (e) a realisation of the limited resources available. We want to know: How can we maximise the limited resources available? The focus is on preparation/risk mitigation, rather than response. Undergirding the proposals in this document is the application of fire safety engineering.

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"A comprehensive introduction to a complex problem – a 'must have' for anyone engaged in fire safety engineering within informal settlements"
Brian Meacham (Meacham Associates, SFPE Past President)

"An important first step in solving the fire problem of informal settlements"
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