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JFPE

Journal of Fire Protection Engineering
22(1) 23–44

DOI: 10.1177/1042391511431508
jfe.sagepub.com
SAGE

Detection of a typical arson fire scenario – comparison between experiments and simulations

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Abstract

Between one and two school fires occur in Sweden every day. In most cases, arson is the cause of the fire. The most severe fires generally start outside the building and spread up along the façade and into the attic through ventilation openings in the eaves. Linear heat detectors can be placed on façades to detect these types of fires. Such devices detect fire when short-circuited at a specific temperature. In this article, an attempt to simulate linear heat detectors is presented. Data from small-scale and full-scale experiments are compared with these simulations. The small-scale experiments and simulations demonstrate that the cable failure model in Fire Dynamics Simulator can be used to predict detection in linear heat detectors that use short-circuiting as the means of signaling an overheated condition. The full-scale experiments provide a measure of the uncertainties involved, as well as the possibility of using simulations of linear heat detectors in a fire engineering design.

Keywords

Arson, heat detection, fire detection, full-scale experiments, CFD, fire modeling, fire engineering

Introduction

Arson fires are a large societal problem in Sweden. According to the national statistics supplied by the Swedish Civil Contingencies Agency, 10–15% of all

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fires yearly in Swedish buildings (approximately 11,000) are caused by arson [1]. In school buildings, however (schools and nursery schools), arson is the cause of more than 40% of the yearly 400–500 fires. At least 50% of these arson school fires are caused by youths, intentionally or accidentally while playing with fire [2].

According to statistics from insurance companies in Sweden, which are collected and presented by the Swedish Fire Protection Association [3], the cost of fires in school buildings is about 500 million Swedish crowns (approximately 70 million USD) yearly. This is more than 10 % of the total cost of fires in Sweden. The majority of these costs originate from just a few school fires. In a previously conducted study at Lund University [4], it was concluded that the most severe fires generally start outside the school building and spread up along the façade and into the attic through ventilation openings in the eaves (Figure 1). The fire can develop and grow in the attic since the roof construction in most cases is combustible. If the attic is not divided into fire compartments, the fire can spread along the entire building and if fire compartmentation is lacking or insufficient between the attic and the area below, the fire can spread to the classrooms underneath. In the cases where there is no detection system on the façade or in the attic, the fire will first be detected when smoke reaches the classroom areas. This means that large parts of the school will be heavily damaged even before the fire service is alerted. Four of the most costly school fires during 2009 had this kind of fire development and these fires corresponded to a total insurance cost of approximately 285 million Swedish crowns (about 40 million USD) [5].

One way to reduce the amount of damage caused by these types of fires is to detect the fire at an early stage, possibly before it spreads to the attic. Two systems that can be used to detect these types of fires are smoke detectors placed in the building attic and linear heat detectors placed on the façade. The purpose of the smoke detectors in the attic is to detect smoke that flows into the attic from the outside through the ventilation openings on the eave. Linear heat detectors are placed on the façades which detect the fire by being short-circuited at a specific temperature [6].

Figure 1. A typical arson fire scenario in Sweden: a small fire is ignited close to the façade, and the fire develops and spreads to the attic where it can develop without being detected.

Some previous research has been conducted in the Nordic countries in this area. SP, Technical Research Institute of Sweden has conducted a series of tests on linear heat detectors and published a report [6] with general advice on where to place linear heat detectors on façades and eaves. The general advice given in the report is based on several full-scale experiments that are supposed to simulate arson fires in garbage bins placed close to a façade. The fuel used in the experiments was propane and the heat release rates ranged between 100 and 150 kW. The experiments were complemented with computational fluid dynamics (CFD) simulations using the codes SOFIE and Fire Dynamics Simulator (FDS). In the report, it is concluded that linear heat detectors should be placed as low as possible on the façade; however not lower than 1 m from the ground.

SP has also, together with the insurer Trygg Hansa [7], conducted four full-scale tests on a building where smoke entrainment into an attic was studied. The experiments were performed on a one-story building fitted with an attic. A 25-mm wide opening connected the attic with the outside for ventilation. Linear heat detectors were placed on the façade and smoke detectors in the attic space with the purpose of comparing the two types of detection systems. Various types of combustibles were used as fire sources. The general conclusion was that the smoke detectors in the attic detected the fire after approximately 1.5 min and the linear heat detectors on the façade around 1 min later.

Other related full-scale experiments have recently been conducted at SP [8] as a part of the investigation of a school fire in the Gothenburg area in Sweden in 2009. The purpose of the experiments was to recreate the fire scene and investigate why the smoke detector activation in the attic was delayed.

All these tests give valuable information on how different detection systems can be used in a typical school façade system. The results in most cases are hard to generalize for use in a fire engineering design. Nilsson [9] has made attempts to use the CFD code FDS to study smoke movement into attics through ventilation openings. However, there is a need to validate these types of simulations to be able to evaluate technical systems to mitigate and eliminate the consequences of the above-mentioned fire scenario. A project has therefore been launched where results from computer simulations are compared with results from full-scale experiments. In the experiments, both linear heat detectors and smoke detection were studied. This article focuses only on linear heat detectors.

The linear heat detector studied in this article is composed of two copper-coated steel wires that are individually insulated with a heat-sensitive polymer. When the polymer insulation is heated to a specified temperature, the conductors will create a short circuit and detection will take place. The cable detects a possible fire along its entire length and can be connected to a fire alarm.

Andersson and van Hees [10] have studied the functional performance of cables in fires. The work performed by Andersson and van Hees has been incorporated into FDS [11] as a cable failure model, called THIEF. The model postulates that thermally induced electrical failure can be predicted via a simple one-dimensional heat transfer calculation, under the assumption that the cable can be treated as a homogenous cylinder. The thermal conductivity and the specific heat are assumed to be constant for all cables. Given assumptions made by Andersson and van Hees, the governing equation for the cable jacket temperature is given by:

$$\rho c \frac{\partial T}{\partial t} = \frac{1}{r} \frac{\partial}{\partial r} k r \frac{\partial T}{\partial r} \tag{1}$$

where ρ, c, and k are the density, specific heat, and conductivity of the solid cable jacket, respectively. The boundary condition at the exterior boundary, $r = R$, is given by:

$$k \frac{\partial T}{\partial r}(R,t) = \dot{q}'' \tag{2}$$

The heat flux, $\dot{q}''$, is assumed to be axially symmetric to the exterior surface of the cable. FDS calculates the radiative and convective heat flux.

This cable failure model has been verified against tests in a project called CAROLFIRE [12, 13] that has been supported by the US Nuclear Regulatory Commission. CAROLFIRE showed that the model works effectively in realistic fire environments. Dreisbach et al. [14] have also validated the model but in full-scale under-ventilated room experiments.

The original intention with the THIEF model was to study effects on electrical cables (e.g. hot shorts and shorts to ground) in order to determine the functional performance of cables in fires. However, since the described linear heat detectors are detecting the fire by means of a short circuit at a specific temperature, the same model could be used to simulate this type of detection and that would be another new application area for the model.

Scope

In this article, an attempt is made to simulate detection times resulting from linear heat detectors used in a typical arson scenario. Small-scale and full-scale experiments are performed and compared to simulations. The small-scale experiments are performed to study the ability of FDS to simulate linear heat detectors and can be seen as a validation exercise. The full-scale experiments are conducted in real outside conditions to get an idea of the uncertainties involved and possibilities for fire safety engineers to use the model for the studied application.

Method

The work presented in this article has been performed in three steps. In the first step, small-scale experiments have been conducted. The small-scale experiments were performed in a fire laboratory, where linear heat detectors were placed on a wall at different heights above a propane burner with a constant heat release rate.

Detector activation times were recorded as well as temperatures in eight thermocouples.

In the second step, full-scale experiments have been conducted. The full-scale experiments consisted of two identical outdoor setups. A fire was ignited against the wooden façade of a one-story building with a small attic space. The façade was fitted with thermocouples and linear heat detectors. Times to detector activation, thermocouple temperatures, as well as mass loss of the fuel were recorded. A similar type of fire was analyzed later in the fire laboratory since the heat release rate could not be measured directly in the field experiment. The fuel mass loss rate from the full-scale experiment and laboratory tests were compared to get an estimate of the heat release rate in the full-scale experiment.

In the third step, attempts were made to simulate the small-scale and full-scale experiments with FDS. The results from the experiments and simulation were compared and analyzed. The first set of experiments is used to validate the THIEF model in FDS, while the second set of experiments provides information on the uncertainty and variation between real life results and simulations.

Small-scale experiment

The small-scale experiments are performed to investigate if the cable model in FDS [11] can be used to predict activation time of linear heat detectors. The cable model is, as previously mentioned, based on the work conducted by Andersson and van Hees [10].

The small-scale experiments were performed in the fire laboratory of Lund University, where two linear heat detectors were placed on a 10-mm thick non-combustible fiber silicate board. The cables were placed at 1 and 1.5 m above a burner.

The linear heat detection cable most widely used in Sweden was used in the experiment. The cable type used is composed of two copper covered steel wires, individually insulated with a heat sensitive polymer. At the rated temperature (105°C), the polymer insulation melts, causing the conductors to short-circuit and generate an alarm signal [15].

Type K thermocouples, with a thickness of 0.51 mm, were also included in the experiment. Eight thermocouples were equally spaced between 0.9 and 1.5 m right above the burner and 40 mm in front of the wall.

Propane gas was used as fuel and the gas flow kept at a constant rate that corresponded to a heat release rate of 10 kW. The burner was a diffusion sand box burner with dimensions 75 × 75 mm. The oxygen depletion method [16] was used to double check the heat release rate. The experiment (cable1) was repeated twice (cable2 and cable3). The experiments lasted for 10 min or until both the cables detected the fire.

The experiments were conducted under a smoke extraction hood. A sensitivity analysis was conducted to investigate whether the extraction flow affected the results. The analysis showed that the differences on the average thermocouple temperatures between tests with and without extraction flow were small. The difference ranged typically from around 0°C to 10°C between TC1 and TC8 (Figure 2). Thus, the effect of the extraction flow was considered to be negligible.

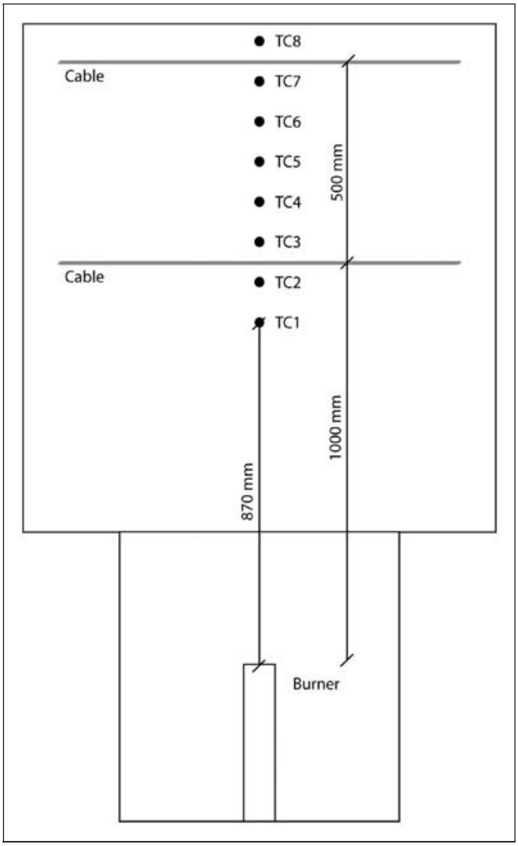

Figure 2. Setup of the small-scale experiment.

Results and analysis

Both cables detected the fire in the first experiment (cable1). The second experiment (cable2) was aborted after approximately 5 min due to equipment failure in the upper cable. The cable closest to the fire had however detected the fire at this time. In the third experiment (cable3), only the cable closest to the fire was activated. The flame heights in the experiments fluctuated between 0.5 and 1.0 m and the mean flame height was visually estimated to be 0.7 m. The results from the small-scale experiments are presented in Table 1.

Figures 3 and 4 clearly show that the temperatures stabilized around 150°C at 1 m above the burner and slightly below 100°C at 1.5 m above the burner. The tests are considered to have good repeatability, and the span of 13 s in detection time for the lowest linear heat detectors (Table 1) is reasonable. The detector placed at 1.5 m activated after 5 min in one experiment and not at all in the other two. This is not

Table 1. Activation times for linear heat detectors in the small-scale experiments.

	Time to detection (s)	
Test	1.0 m	1.5 m
cable 1	43	245
cable 2	38	No activation[a]
cable 3	51	No activation

Note: [a]cable2 was aborted after 275 s due to malfunctioning equipment.

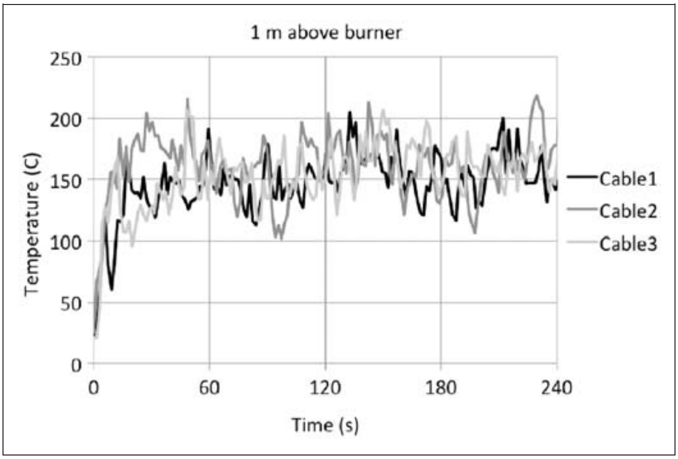

Figure 3. Temperatures 1 m above the burner.

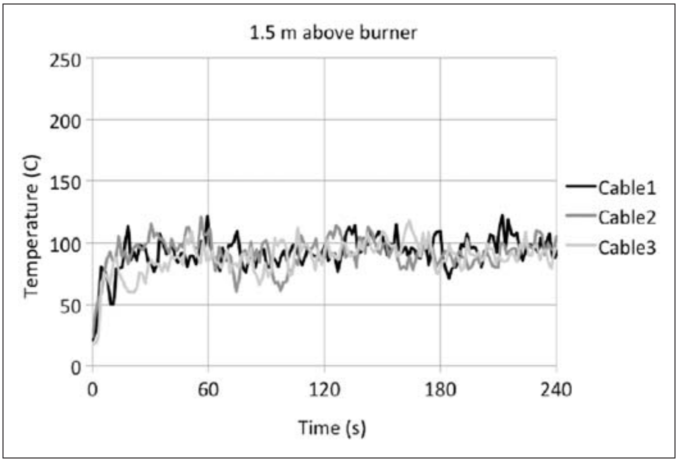

Figure 4. Temperatures 1.5 m above the burner.

surprising since the temperatures at that height are close to the detection temperature of 105°C. The figures also show that the plume temperatures stabilized very quickly (less than 20 s).

Full-scale experiment

The full-scale experiments are conducted in real-scale conditions to get an idea of the uncertainties and possibilities of using simulations of linear heat detectors in fire engineering design and should therefore not be considered as validation experiments since not all parameters could be measured accurately (e.g. wind conditions).

Weather conditions

Since the experiments were performed outdoors, the surrounding conditions were hard to control. It rained slightly during all the experiments and there was some wind from east–northeast, which was straight onto the façade. The wind direction was however not stable at any time and nearby obstacles created turbulence. The wind speed varied between 2 and 3 m/s. The ambient temperature was around 12°C.

Fire source

The typical initiating fires during arson events in Swedish schools have been identified in a previously conducted case study [4]. Typical fire sources for a deliberately lit fire at a façade are various combustible materials that can be found in and around the school, such as waste material. In some cases, even flammable liquids are used as accelerants. The most common accelerant used in incendiary fires is gasoline, according to Babrauskas [17]. Therefore, a wastebasket fire with gasoline as an accelerant was chosen as the fire source. The waste consisted of paper and the weight was approximately 300 g. In the two experiments, gasoline was poured onto the paper before it was ignited. The amount of gasoline was approximately 350 g.

The fire was also analyzed in the fire laboratory since the heat release rate could not be measured in the field experiment. Both mass loss and heat release rate were measured in the fire laboratory, the latter using the oxygen depletion method [16].

Experimental setup

The field experiments were conducted against the façade of an existing house. The one-story building was fitted with a small attic space. In the experiments, the façade was clad with pine. The experiment was repeated once (test 2).

The experiment was conducted at a place on the façade, where the height to the eave was 3.1 m (Figure 5). The eave was 260 mm wide and there was a 25-mm ventilation opening that connected the attic space with the outside. The attic space

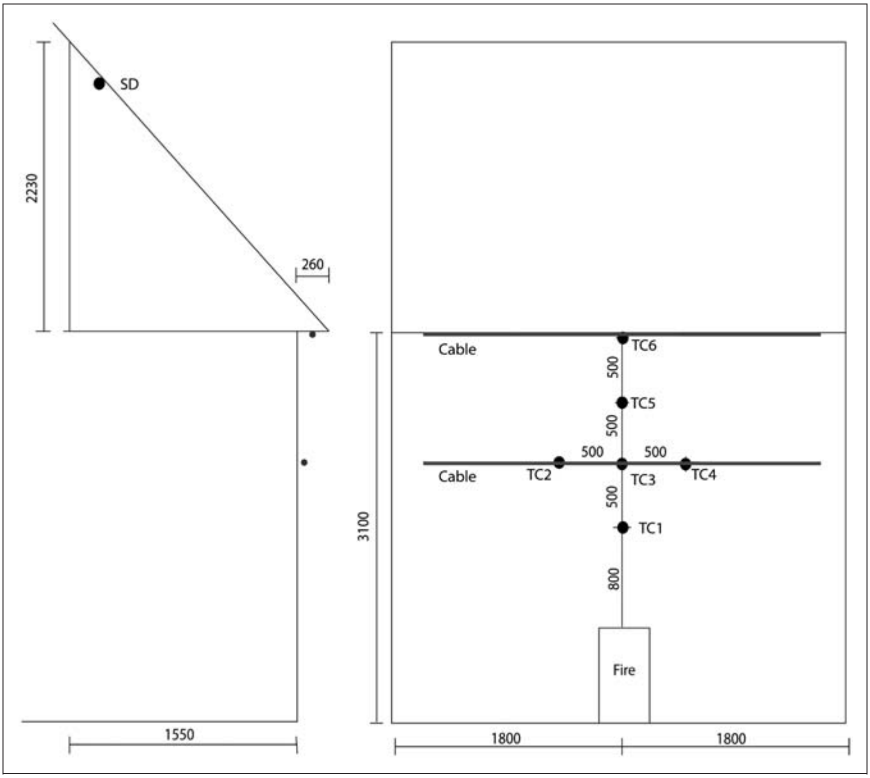

Figure 5. Setup of the full-scale experiment showing the placing of smoke detectors (SDs) and thermocouples (TC).

was 1.6×3.6 m and 2.3 m at the highest point. The attic had a 0.8 m wide and 2 m high door that was connected to an adjacent larger volume. The door was open during all experiments. Both experiments were conducted at the same place on the façade, but the wood cladding on the façade was replaced between the two tests.

Temperatures were measured with type K thermocouples, with a thickness of 0.51 mm, at six places on the façade, four at different heights (0.8, 1.3, 1.8, and 2.3 m) right above the fire source and one on each side, 0.5 m from the centerline, and 1.3 m above the fire source (Figure 5). Two linear heat detectors were used. One was placed on the façade 1 m below the eave and the other one was placed on the eave, at a distance of 50 mm from the façade surface. Four smoke detectors were placed in the attic space. The detectors used the scattered-light principle and two of them were fit with two sensors for optical forward and backward scattering. Smoke spread to the attic but smoke detection in the attic is not the focus of this article and will therefore not be described further.

The fire sources used in these experiments were similar to the fire source tested in the laboratory and described above. The mass loss of the fuel was recorded with a load cell during each experiment. The mass loss is compared to the results from the fire laboratory tests (Figures 8 and 9).

Results and analysis

The results from the two full-scale experiments (test1 and test2) are presented in Figures 8–13 and Table 2.

The lowest line detector detected the fire in less than 1 min, while the detector at the eave never detected the fire. The pine cladding was somewhat charred after the fire but it did not spread vertically to the façade or eave in either of the two experiments.

The weight of the fuel was measured during the full-scale experiments in order to be able to calculate the mass loss rate; however, no measurements of the heat release rate were made. To be able to estimate the heat release rate, two fire tests with similar fires were conducted at the fire laboratory. The fuel consisted of just as much paper as in the full-scale experiments; however, only two-thirds of the

Table 2. Detection times for linear heat detectors in the full-scale experiments.

	Time to detection (s)	
Test	1.3 m	Eave
test1	59	No activation
test2	47	No activation

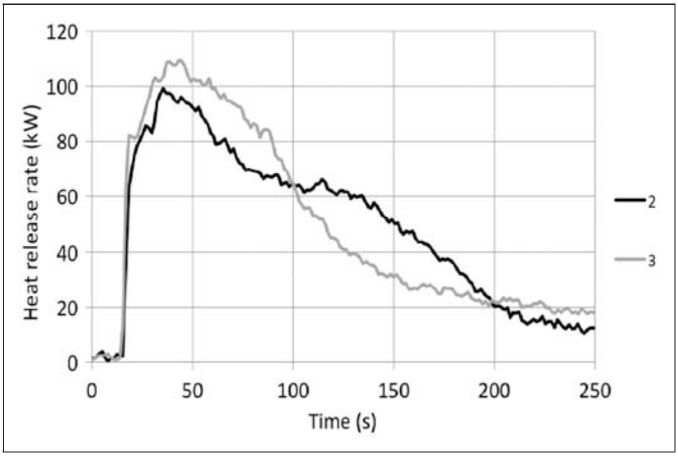

Figure 6. Heat release rate as measured in the laboratory.

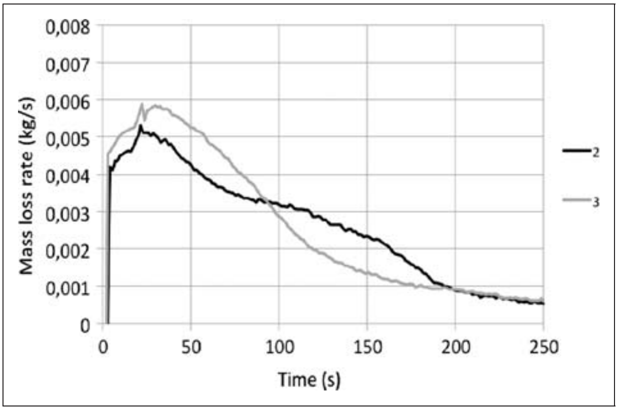

Figure 7. A 30 s average of the mass loss rate as calculated from laboratory weight measurements.

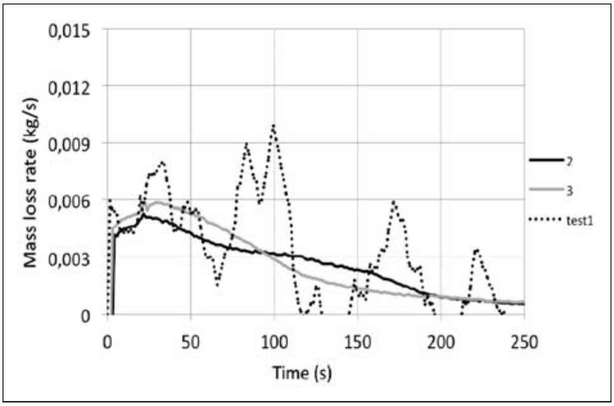

Figure 8. Mass loss rate in test1 compared to that measured in the laboratory.

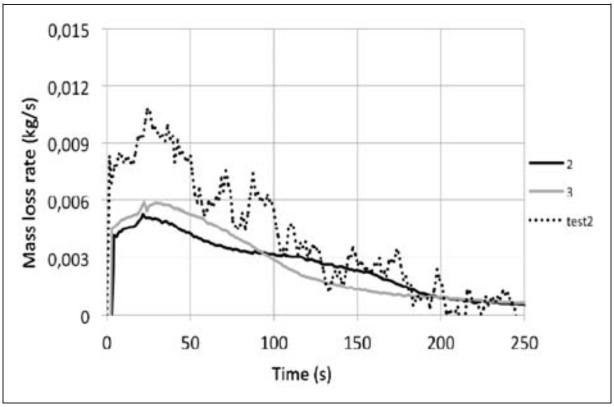

Figure 9. Mass loss rate in test2 compared to that measured in the laboratory.

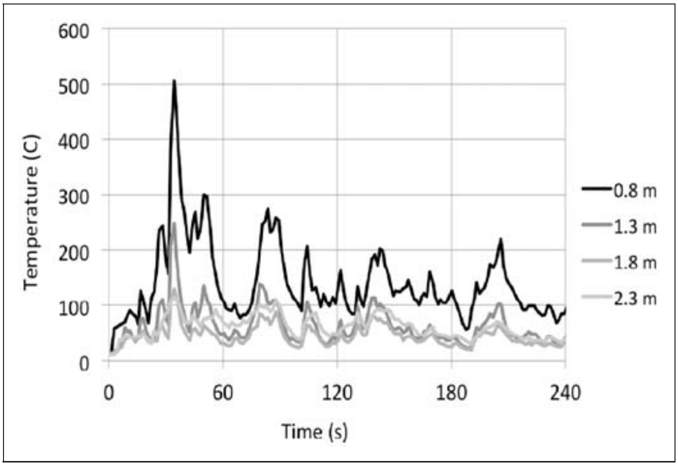

Figure 10. Vertical temperatures at TC1, TC3, TC5, and TC6 right above the fire in test 1.

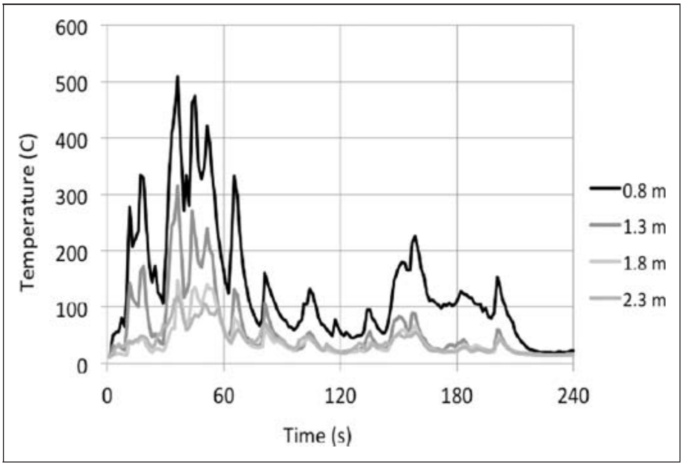

Figure 11. Vertical temperatures at TC1, TC3, TC5, and TC6 right above the fire in test 2.

amount of gasoline could be used in the laboratory in comparison with the full-scale experiment due to safety reasons. Heat release rate and weight loss were measured in the laboratory tests. The heat release rate was measured with the oxygen depletion method [16]. The results (Figures 6 and 7) show that the peak heat release rate occurs at the same time and that the burning time is roughly the same in both experiments. The repeatability of the two tests is considered to be good with regard to the uncertainty connected with the composition of the fuel, i.e., the packing of the paper in the wastebasket and distribution of gasoline on the paper.

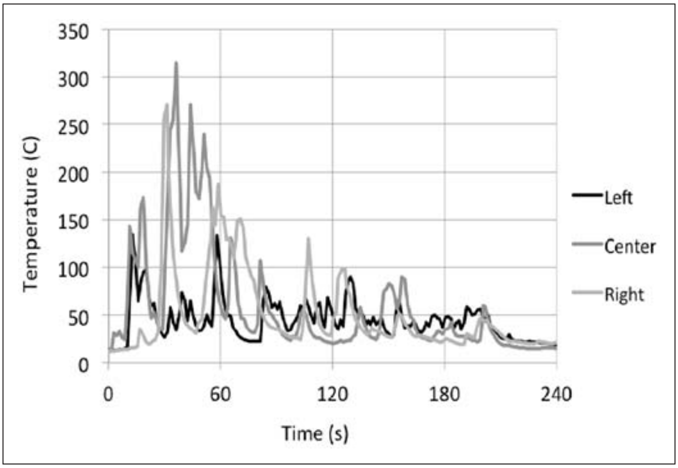

Figure 12. Horizontal temperatures, TC2, TC3, and TC4 in test 1.

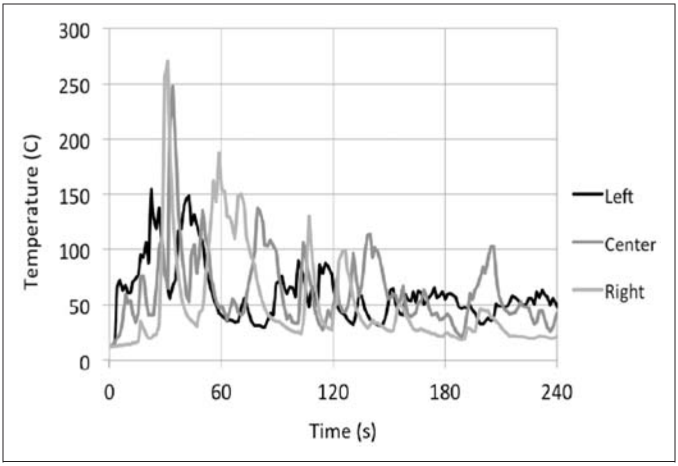

Figure 13. Horizontal temperatures TC2, TC3, and TC4 in test 2.

The mass loss recorded in the laboratory was compared with the mass loss in the full-scale experiments to get an approximation of the heat release rate during the experiments and see the variation between the tests.

A 30 s average of the mass loss rates is presented and compared to the measured mass loss rate in the laboratory in Figures 8 and 9. The mass loss rates in the full-scale experiments fluctuated a great deal and were generally higher than in the laboratory experiments. It is therefore probable that the heat release rates in the full-scale experiments were higher than in the small-scale experiments (Figure 5).

The apparent reason for this is that more gasoline was used in the full-scale experiments. The fluctuations in the two full-scale experiments are considered to be due to wind effects and outdoor conditions. It can also be seen that the mass loss rate in test 2 is steadier than in test1, which is due to the fact that the wind was steadier in test 2.

Figures 10–13 illustrate that the temperature decreases with distance from the fire. The maximum temperatures occur after approximately 40–50 s in both test1 and test 2. From Figures 12 and 13, it is obvious that the temperatures are not symmetrical about the vertical axis, most likely due to wind effects.

Simulations

The computer simulations were performed with FDS version 5.5.2, revision 6799. Simulations have been performed for both the small-scale and full-scale experiments. In both cases, grid sensitivity analyses showed that the grids used were appropriate.

Small-scale experiment

The setup as described above was used in the cable failure model in FDS to represent the linear heat detectors. The density (0.026 kg/m$^{3)}$, thickness (4.3 mm), and jacket thickness (1.2 mm) of the cable were inputs in the model. The simulated domain was $1.66 \times 1.2 \times 2.25$ m and multiple meshes were used with a uniform grid size of 10 mm. This grid size gives a characteristic fire diameter divided by

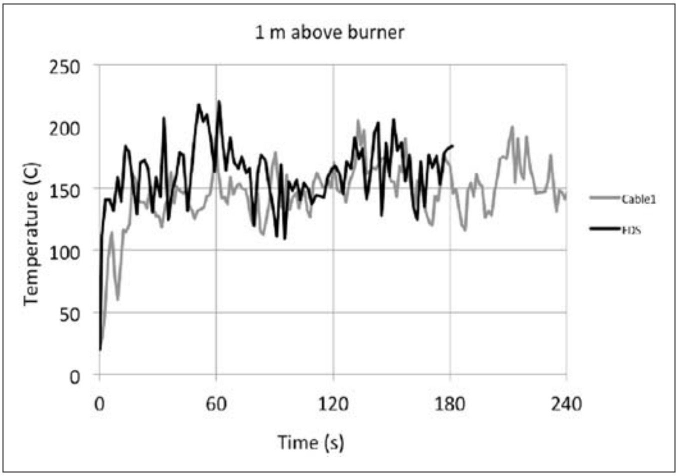

Figure 14. Thermocouple temperatures 1 m above the burner (simulation and experiment).

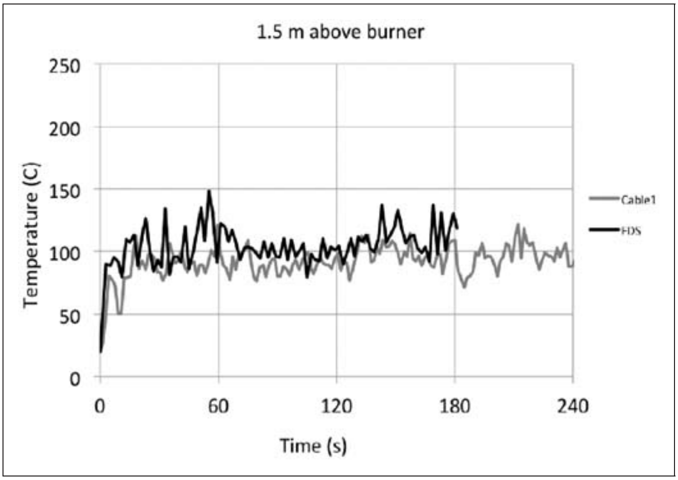

Figure 15. Thermocouple temperatures 1.5 m above the burner (simulation and experiment).

Table 3. Detection times for linear heat detectors in the simulation of the small-scale experiment.

	Time to detection (s)	
	1.0 m	1.5 m
FDS simulation	43	No activation[a]

Note: [a]The simulation was aborted after 300 s, and no activation occurred during this time span. Extrapolation of the temperature within the cable indicates that activation would not occur even with extended simulation time.

nominal size of a mesh cell of about 15. The flow from the smoke extraction fan in the laboratory was not included in the simulation. It was shown in the previously mentioned sensitivity analysis that its effect on thermocouple temperatures was small. The heat release rate was, as in the experiments, 10 kW. Standard combustion, radiation, and turbulence settings in FDS were used.

Results and analysis. The results from the simulation of the small-scale experiment are presented in Figures 14 and 15 and Table 3. Results from the small-scale experiments (cable1) are included in the figures for comparison.

The detection time for the lower linear heat detector is within the span of detection times in the experiments (Table 1). The upper detector did not detect the fire. This is not surprising since temperatures are stable at around 100°C (Figure 15).

Table 4. Detection times for linear heat detectors in the simulation of the full-scale experiment.

	Time to detection (s)	
	1.3 m	Eave
FDS simulation	41	No activation[a]

Note: [a]The simulation was aborted after 300 s, and no activation occurred during this time span. Extrapolation of the temperature within the cable indicates that no activation would occur even with extended simulation time.

Figures 14 and 15 demonstrate that the FDS simulation predicts the thermocouple temperatures in the conducted experiments very well. Mean values every 2 s from the simulations are shown in Figures 14 and 15.

Full-scale experiment

The purpose of the simulation was to demonstrate a typical fire engineering analysis, where best practice is used, and compare the results to data from a real fire. No refinement of the FDS input file was made to fit the experimental data. An average of the heat release rate from the laboratory experiments (Figure 6) was used in the simulations. The geometry as described above was used. Thermocouple and linear heat detectors were placed as in the experiments. Thermocouples of the same size as in the experiments were used in FDS to capture heat transfer and radiation losses to and from the thermocouples. Smoke detectors were not included in the simulation since the focus was on linear heat detectors. No weather effects were considered other than the ambient temperature.

The simulated domain was $3.6 \times 2.4 \times 5.4$ m and multiple meshes were used with a grid size of 15 mm near the fire and 30 mm further away. These grid sizes give a characteristic fire diameter divided by nominal size of a mesh cell, of about 25 and 13, respectively.

Results and analysis. The results from the simulation of the full-scale experiment are presented in the following figures and Table 4. Results from the full-scale experiments (test2 and test3) are included in the figures for comparison.

The simulated detection time for the lower linear heat detector is 6 and 18 s faster than in the experiments (Table 2). This is expected since the temperatures are higher in the simulation (Figures 16–19).

Figures 16 and 17 illustrate that temperatures in the simulation are generally higher than those in the performed tests. Figures 18 and 19 show that the simulated temperatures are more steady and lower than in the experiment. In the experiment, the flame fluctuated in the horizontal direction and leaned dominantly to the right due to the fact that the wind was coming from the left, while the

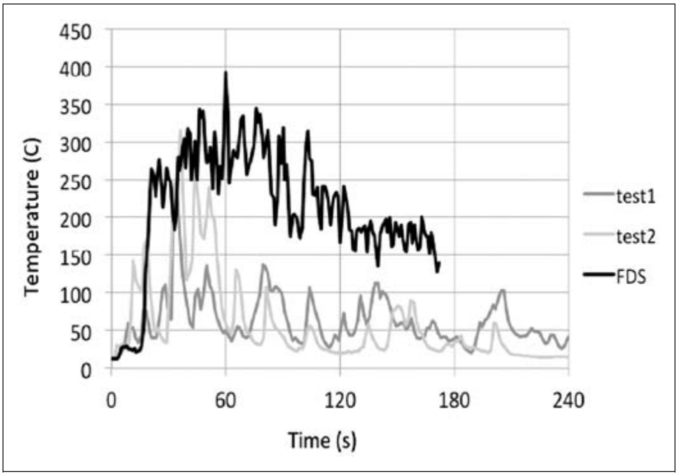

Figure 16. Simulated temperature 1.3 m above the fire (TC3) and compared to experimental results.

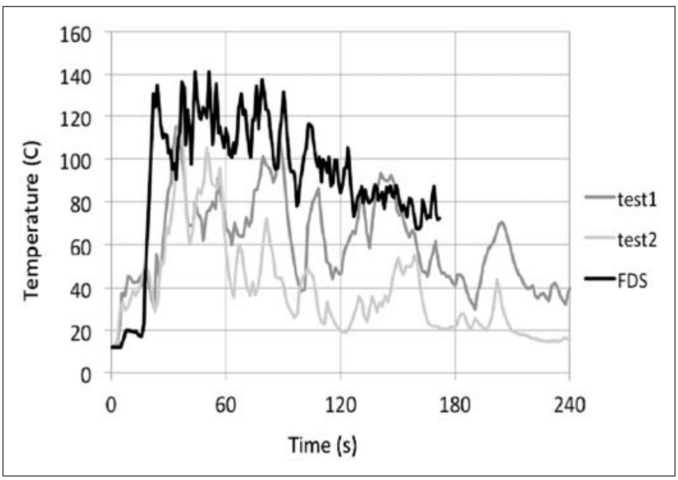

Figure 17. Simulated temperature 2.3 m above the fire (TC6) and compared to experimental results.

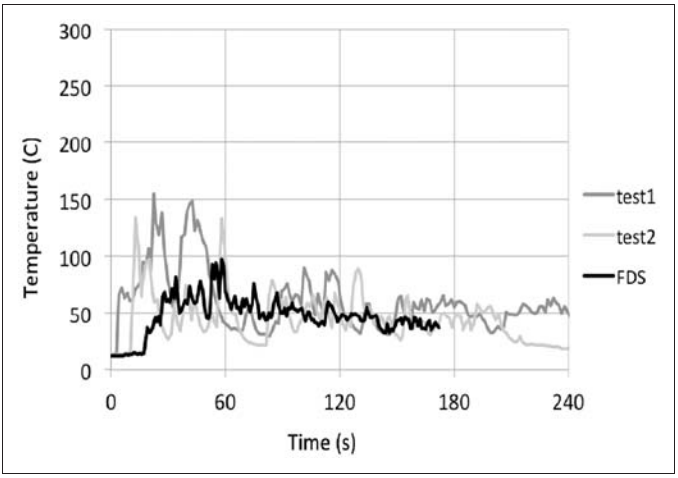

Figure 18. Temperatures 1.3 m above and 0.5 m to the left of the fire (TC2).

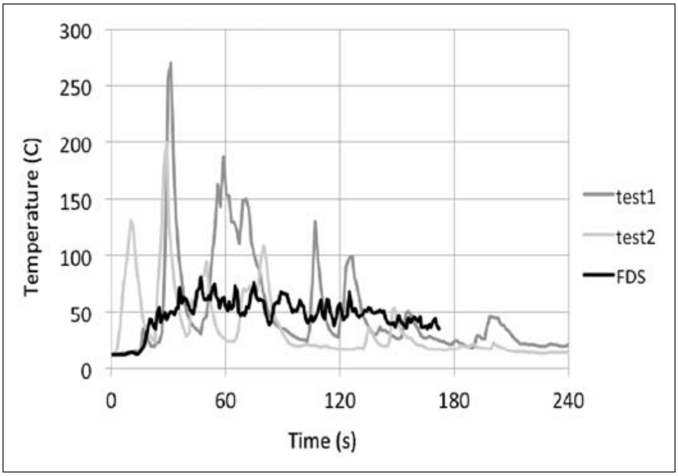

Figure 19. Temperatures 1.3 m above and 0.5 m to the right of the fire (TC4).

horizontal fluctuations in FDS were small in comparison since no wind effects were considered.

Discussion

Small-scale experiment

The small-scale experiments were performed indoors in a rather controlled environment, and the heat release rate and properties of the fuel were well known.

A sensitivity analysis regarding ventilation conditions was conducted to investigate how the forced flow affects the results. The analysis showed that the ventilation conditions did not affect the results of the experiments in any considerable extent. The temperature predictions 1.5 m above the burner were about 10°C higher with FDS, and the predicted detection time of the linear heat detector placed 1 m above the burner was in the range of the results from the experiments. The upper detector (placed at 1.5 m above the burner) did activate in one of the experiments. In the test where it activated (cable1), it happened after more than 5 min. Figure 4 demonstrates that the temperatures are stable around 90–110°C which is close to the detection temperature (105°C). It is therefore not surprising that there is some difference in detection time between the two tests. The temperature at the upper detector will, according to the FDS simulations, stabilize around 100°C, which seems reasonable with respect to the experimental results.

The cable failure model in FDS has been developed to simulate cable failure in fires due to a lack of functional performance; however, in this case, the model is used to simulate detection time with a linear heat detector. The principles of cable failure and linear heat detector activation, are in this case, the same, although the cable model in FDS has not been used previously for detection purposes. The simulations of the small-scale experiments have shown that the cable failure model can be used for this application and therefore widens the application area. This is an important conclusion since it can be used as a tool in the future fire safety engineering design of detection systems without having to run tests for all possible configurations.

Full-scale experiments

The registered temperatures at the thermocouples in the full-scale experiment clearly show that the flames and fire plume are not axis-symmetrical. The experiments are considered to represent a typical outside arson fire, where weather can have a large affect on the fire development and fire spread. Using the best engineering practice, it is hard to recreate the fire scenario in FDS. When comparing the experimental results with the results from the simulation, it is obvious that the inputs used are not enough to get conservative results. In this case, the wall temperatures are overestimated and the detection time is underestimated in FDS. It can be seen that the difference in gas temperatures between tests is greater than the difference between tests for the detection time of the linear heat detector. This is due to the fact that thermocouples measure temperature at a single point, while the linear heat detector detects along the entire cable length. Thus, the cable was affected by heat from the fire even though the flames leaned away from the vertical axis.

The mass loss rates were initially higher and fluctuated more in the outdoor environment than in the laboratory. The mass loss rate is dependent on radiative heat transfer from the flames and plume toward the fuel. When wind causes the flames and plume to fluctuate, it will affect the radiation to the fuel, thus causing the mass loss rate to vary and be more fluctuating. The higher mass loss rate is however most likely caused by the somewhat larger amount of gasoline used in the full-scale experiment compared to the laboratory tests, which were used as input to the simulation. The purpose is however not to perform a posteriori simulations to validate FDS for this application but to get an idea of the uncertainties involved.

The weather conditions and especially the wind have a very large influence on the final results. Figures 10 and 13 show that the temperatures vary between the different tests due to wind effects. The wind effects have not been taken into account in the simulations that were performed. In fire safety engineering, it is hard to take weather effects into account since it is not always obvious which conditions are conservative. In this case, where the wind is not included in the model, the model detection time is underestimated. A design scenario with no wind effects does not necessarily amount to a proper design scenario for linear heat detectors placed on a façade. It is possible to simulate wind effects in FDS by prescribing a velocity of the wind at an exterior boundary but it is not possible at the moment to capture turbulence in the wind before it enters the domain, which is crucial to being able to recreate a certain scenario. It would also be necessary to study different wind directions and wind speeds, which in all makes it a complex problem.

The full-scale experiments are very sensitive to the weather conditions. If the experiments would have taken place another day with other weather conditions, the results would have been different and maybe more like the results from the FDS simulations. This type of situation is a challenge for fire safety engineers and the inputs to models used must be based on good engineering judgment. This article gives an indication of differences that can be expected between real life results and design calculations. It is therefore recommended to perform some kind of sensitivity analysis when conducting this type of fire engineering design. The sensitivity analysis can be made quantitative by varying the different input parameters in the design calculations.

In future research, it could be interesting to study how smoke detector activation in attics can be modeled and consequently compared to linear heat detectors on the façade for different scenarios, both in regard to heat release and fuel and also in regard to different weather conditions.

Conclusions

The simulation of the small-scale experiments has demonstrated that the cable failure model in FDS can be used to predict linear heat detector activation with sufficient accuracy. Hence, it is shown that the application of FDS can be extended. The cable model is a good tool for fire engineers to use but as with all models, it must be used with caution.

The applicability is demonstrated in this article with experiments and simulations. The full-scale experiment and simulation show how difficult it is, even with good engineering practice, to predict smoke and fire spread in an outdoor scenario. The uncertainties in fire safety engineering are a challenge and models must be based on good engineering judgment. It can however be seen that the uncertainty in predicting activation time of the linear heat detector is much smaller than that for the temperature field prediction.

Acknowledgments

The research presented in this article has been conducted within a multidisciplinary project initiated by The Swedish Fire Research Board (Brandforsk). The project is financed by The Swedish Civil Contingencies Agency, The City of Malmö, Svenska Kommun Försäkrings AB, Kommunassurans Syd, Länsförsäkringar, Trygg-Hansa, Göta Lejon, St Eriks försäkring, Stockholmsregionens Försäkrings AB, Förenade Småkommuners Försäkringsbolag, and KommuneForsikring which are gratefully acknowledged.

The Crafoord Foundation, which has financed large parts of this study, is also gratefully acknowledged. Furthermore, the rescue services in the city of Värnamo, Sweden, Jan Blomqvist, Siemens Sweden, Lars-Gunnar Klason, SP, Stefan Sjökvist, Termisksystemteknik, Janne Sørensen, and Clara Rossignol are all gratefully acknowledged for their help during the full-scale tests.

Finally, the simulations were performed within the CECOST (Center of Excellence in Combustion Science and Technology) solid combustion project. The authors acknowledge therefore also the financial support by CECOST through the Swedish Foundation for Strategic Research, SSF, and the Swedish National Energy Administration, STEM.

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