A DECADE OF SCANDINAVIAN RESEARCH AIMED AT BENEFITING THE FIRE SERVICE

Dr. Björn Karlsson & Dr. Stefan Svensson
Iceland Fire Authority, Reykjavik, Iceland, and Swedish Civil Contingencies Agency, Revinge, Sweden

ABSTRACT

This paper attempts to summarize some of the fire research work aimed at benefiting the fire service carried out in Southern Scandinavia over the last decade or so. More specifically, the paper will concentrate on such research carried out by workers linked to the Department of Fire Safety Engineering and Systems Safety at Lund University. The paper addresses work on flashover, backdraft, ventilation, including positive pressure ventilation, suppression and tactics, to name a few topics.

INTRODUCTION

In this paper we shall attempt to give a brief overview of the fire research work which has been conducted in past years in Scandinavia, where the aim has been to benefit the fire service. The word “research” can be used to describe a myriad of activities, but here we shall limit ourselves to research which uses the scientific method, where scientific information and theories on subjects such as fire chemistry, enclosure fire dynamics, fluid dynamics, active fire protection systems and tactical research are used for the explanation of the nature of fire development and its influence on constructions and humans.

In Scandinavia, such scientific work on fire safety has over the last 40 years been conducted at the Department of Fire Safety Engineering and Systems Safety at Lund University and the department can be seen as the pioneer of fire safety research in Scandinavia. This is especially true of research aimed at benefiting the fire service. Although fire safety research has also been conducted elsewhere in Scandinavia, we shall here concentrate on the research work which is initiated by persons with a strong link to the Department of Fire Safety Engineering and Systems Safety at Lund University. Also, there is no clear and simple distinction between fire research which does or does not benefit the fire service. Given these limitations it is clear that we shall only present a limited part of the intended topic of this paper. The purpose of our endeavour is mainly to show the diversity of the topics covered that may be of interest to the fire service.

FLASHOVER, BACKDRAFT AND SMOKE GAS EXPLOSION

The flashover phenomenon has played a central role in describing fire growth in buildings and the term is used by the fire service as well as professionals in science and engineering. Whereas scientists and engineers use the term to distinguish between the growing fire and the fully developed fire, often for building design purposes, the fire service use the term in training and for decision making when planning and extinguishing operations. Several other terms, describing phenomena such as backdraft and smoke gas explosion, have been used in conjunction with the term flashover and considerable confusion has arisen as to the meaning of these and other related terms. In addition, the phenomena themselves pose a real threat to fire fighters during fire and rescue operations and their understanding of conditions at a fire scene is crucial for their own safety.

The Swedish Rescue Services Agency had for some decades been developing and using a training program for fire fighters to enhance their understanding and experience of the flashover phenomenon. There was, however, considerable controversy with regards to the terms used in the training program and as a result the Swedish Rescue Services Agency commissioned the Department of Fire Safety Engineering and Systems Safety at Lund University to carry out a two year research project on the subject [1]. The main goal of the project was to

- clarify the terminology used when describing the phenomena of flashover, backdraft and smoke gas explosion
- increase understanding of the most dominant thermal and chemical processes involved when these phenomena occur in practice
- produce a bases for teaching material to be used by the Swedish fire brigades

With regard to terminology, it was found [2] that the three terms flashover, backdraft and smoke gas explosion would suffice to describe the most common hazardous phenomena which occur in building fires when the fire exhibits a very sudden and dramatic change in development. Other frequently used terms, such as rollover, flameover, lean flashover, rich flashover, etc, were found to be superfluous, confusing or misleading. Drysdale [4] had earlier voiced concern over these controversies and the work carried out in the project was to some respect inspired by [4] and earlier work from the UK and the USA [3], [5].

The Swedish Rescue Services Agency has, through suggestions from a working group of Swedish experts, decided to use the following definitions of the phenomena [6]:

Flashover: "During a compartment fire a stage may be reached where the thermal radiation from fire, the hot gases and the hot enclosure surfaces cause all combustible surfaces in the fire room to pyrolyse. This sudden and sustained transition of a growing fire to a fully developed fire is flashover".

Backdraft: "A backdraft is the combustion of unburned smoke gases, which can occur when air is introduced into a room where the oxygen content is significantly reduced due to the fire. Combustion can then occur more or less rapidly ".

Smoke gas explosion: "When smoke gases leak into an area adjacent to the fire room, they may mix very well with air. This mixture can expand into the whole or parts of the volume and fall within the flammability range. If the mixture ignites the pressure may increase significantly. This is known as a smoke gas explosion".

Nevertheless, the nature of the abovementioned phenomena is such that no clear-cut definition can distinguish between the very many processes that are involved. These thermal and chemical processes can lead to the occurrence of the phenomena in a multitude of ways. Furthermore, the phenomena themselves are closely related and can in some cases be difficult to distinguish; a backdraft can result in flashover, an underventilated fire can result in a powerful backdraft, which could possibly be called a smoke gas explosion, etc. It is therefore important to have some understanding of the processes that lead to the occurrence of the phenomena.

Fire is a physical and chemical phenomenon which is strongly interactive by nature. The interactions between the flame, its fuel and the surroundings can be strongly non-linear and quantitative estimation of the processes involved is often complex.

In order to introduce the most dominant of these processes, a simplified qualitative description of the main thermal and chemical phenomena associated with enclosure fire growth was presented [2]. The discussion was divided into two parts; the thermal processes that transfer heat to the fuel packages, causing an increase in energy release rate and; the chemical processes that may result in the accumulation of unburned fuel and rapid ignition of the hot gases. These processes can interact in various ways and lead to either backdraft or flashover or both backdraft and flashover.

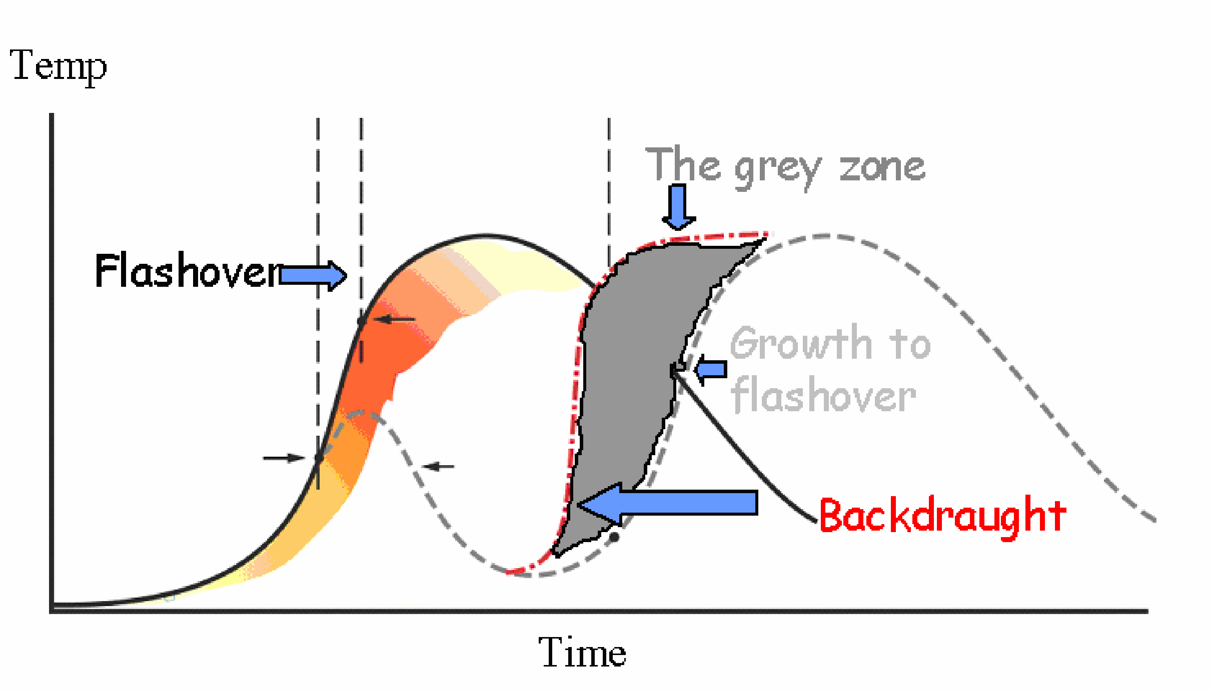

Figure 1: Enclosure fire development in terms of gas temperatures; some of the many possible paths a room fire may follow

The work presented in [1] finally lead to a textbook for fire fighters being published [6] (available in Swedish and English), currently used in the training of fire fighters in Sweden.

BACKDRAFT

The work presented in [1,2] found that research in the area of the under-ventilated fire has not been conducted at the same rate as the well-ventilated fire, mainly due to the very complex physical and chemical processes that occur during the under-ventilated fire. However, it is the under-ventilated fire that the fire service in most cases face when arriving at the scene of a fire. Research regarding the growth of the under-ventilated fire, where a great quantity of unburned gases accumulate, is therefore of great importance in the development of fire suppression tactics and preventive measures. Therefore, a backdraft container was built at the Fire and Rescue Training Facility at Revinge, Sweden, to be used as an experimental apparatus and as a demonstration device for the backdraft phenomena. It was therefore important that the backdraft could be visualized properly.

In order to do this a window was installed on one long side of the container. Ignition of unburned gases in the container will generate a deflagration, which will cause an increase of pressure in the compartment. In order to protect the glass and the container, it was necessary to install a pressure relief panel. Figure 2 shows the short-end of the container with the pressure relief panel in a closed position.

Many experiments have been conducted in the Revinge container, the initial ones by Gojkovic [7], where a more detailed description is given of the experimental apparatus. Much work has since been carried out where CFD models have been tested and further developed to attempt simulation of the full backdraft process, including the combustion phase. The work also included a very detailed study of the gravity current of fresh air entering the container shortly before the onset of the deflagration and very rapid combustion [7, 8, 9]. Also, studies on the influence of possible obstacles, such as furniture, on the gravity wave and the combustion process were conducted [10, 11].

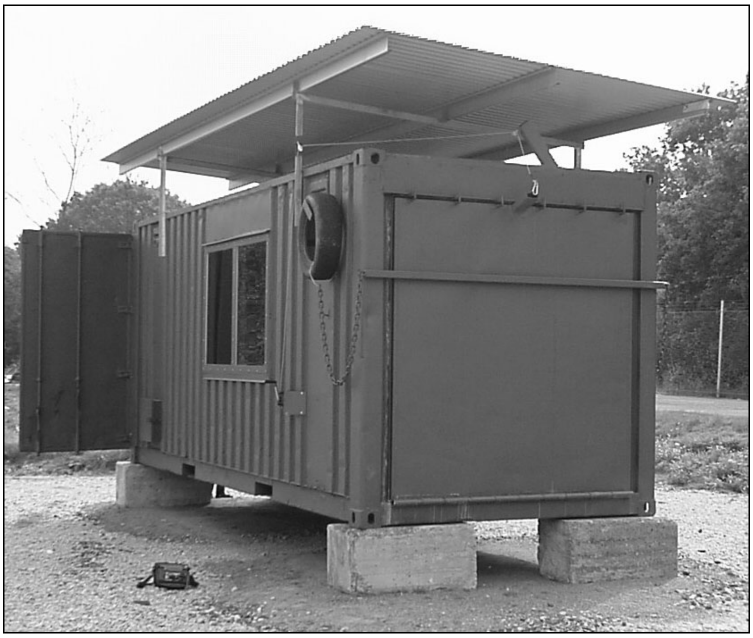

Figure 2: The short-end of the backdraft container with the pressure relief panel in its closed position.

An attempt was also made to integrate theoretical CFD (Computational Fluid Dynamics) calculations with practical fire fighting tactics commonly used when arriving at the scene of an underventilated fire [12]. It is shown that CFD has a great potential in creating greater understanding and efficiency estimation of fire fighting tactics. The basic scenario tested consists of a 3 room apartment. Each room measures 4 x 4 m and is 2.8 m high. There are 3 doors that measure 0.80 x 2.0 m, 2 connecting the different rooms, and one front door connecting room 1 to the outside, and that opening corresponds to the opening at the start of the simulation. Room 3 has a window that is opened in Scenarios 3 and 4. The geometry is shown in Figure 3 below.

The studied tactics were:

- Scenario 1: Reference scenario where no actions are taken.
- Scenario 2: A life-saving operation where fire fighters do enter the apartment.
- Scenario 3: Natural ventilation of the apartment by opening a window at the back of the building.
- Scenario 4A: Ventilation of the apartment using positive pressure ventilation (PPV) at low flow rate 3.73 m^3/s.
- Scenario 4B: Ventilation of the apartment using positive pressure ventilation (PPV) at high flow rate 5.38 m^3/s.
- Scenario 5: Incorrect use of PPV at high flow rate 5.38 m^3/s.
- Scenario 6: Dilution of the unburned gases, by use of water spray before opening. 4 different levels of dilution are simulated, from 25% to 10% of unburned gases.

The CFD calculations proved to be very useful to estimate the efficiency of the different fire fighting tactics, as well as for training and recommendations, being a good complement to fire fighters experience. The choice of tactics depends essentially on the conditions on the fire scene, whether there are people/victims still in the building or not, the risks you are willing to take and what resources in terms of personnel and equipment that are available. Further details are given in [12].

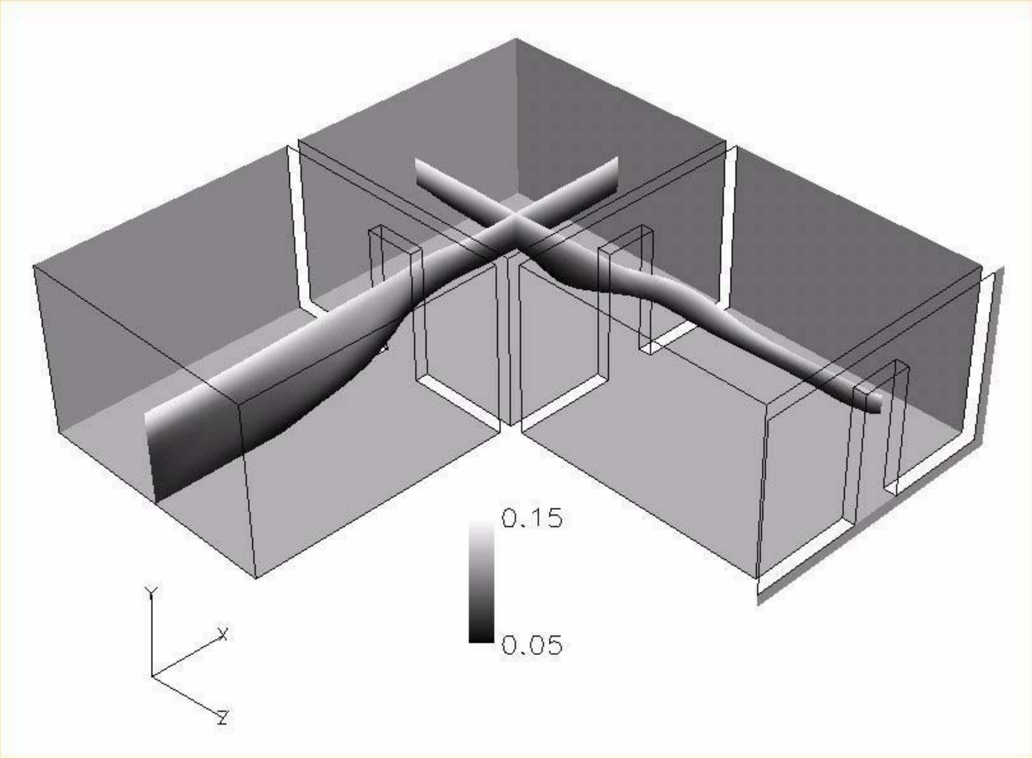

Figure 3: The flammable region 40 seconds into the simulation of Scenario 1.

VENTILATION, INCLUDING POSITIVE PRESSURE VENTILATION (PPV)

A number of experimental studies were carried out to investigate the effect of measures taken by fire and rescue services, including positive pressure ventilation, and to provide fire & rescue services with qualitative data that can be used as a basis for decision making on the fire ground. In the study described in [13] 15 experiments were carried out in a fire fighter training facility (concrete/light-weight concrete) where a 0.50 m diameter heptane pool burned for approximately 12 minutes with a heat release rate of approximately 370 kW. Positive pressure ventilation was provided by a fan with a nominal flow of 2.7 m^3/s.

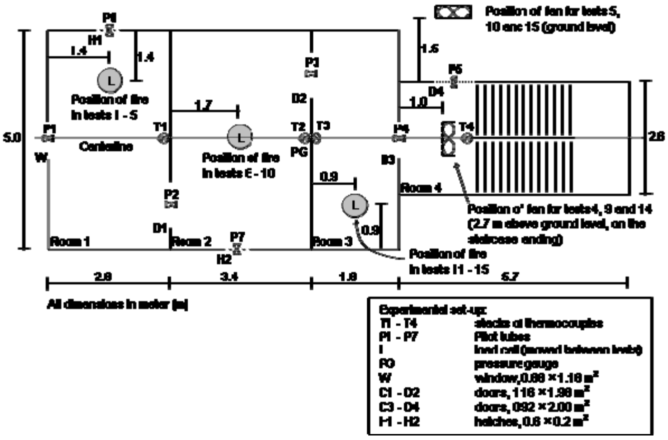

Figure 4: The layout of the experiments described in [13].

The scenarios studied were:

A. via staircase (access route through D4, Room 4, D3), window (W) closed
B. via window (W), door between staircase (Room 4) and apartment closed (D3)

C. via staircase (access route through D4, Room 4, D3), window (W) open
D. via staircase (access route through D4, Room 4, D3), window (W) open, PPV, fan positioned in Room 4
E. via staircase (access route through D4, Room 4, D3), window (W) open, PPV, fan positioned outside door to staircase (D4)

Measurements were made of fuel mass loss rate, temperature and pressure at several locations. The paper concludes that positive pressure ventilation (PPV) increases the mass loss rate of fuel, consequently increasing burning rate of the fire, which could be expected. Working conditions for fire fighters are improved by PPV, but the lives of any victims trapped in an apartment on fire are jeopardised and the risk of fire spread to adjacent rooms will increase. Co-ordination of different measures at a fire scene is crucial and the importance of command and control is prominent.

The work described in [14] and [15] had similar objectives but the experiments were made in a larger scale. Figure 5 shows the layout for the experiments described in [14]. Five tests were performed in a large hall measuring 39 m long, 11.2 m wide and 8.1 m in ceiling height. Approximately 25 liters of methanol were burned with a rate of heat release of appr. 1.0 MW. Positive pressure ventilation was provided by a standard type fan, with a nominal flow of 4.5 m^3/s.

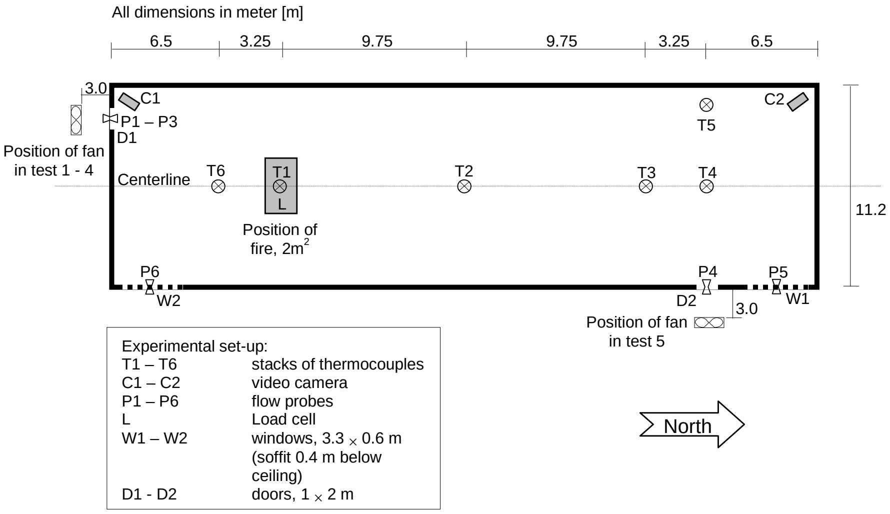

Figure 5: The layout of the experiments described in [14].

Five different scenarios were studied with both natural ventilation through doors and windows as well as PPV with a fan positioned in front of one of the two doors.

Figure 6 shows the layout of the experiments described in [15]. Here, 43 experiments were conducted on the first, second, and third floors of a three-storey brick building with wooden trusses. Four different fans with varied characteristics were used to study the effect of distance between fan and inlet, size and numbers of outlets, and volume of the building on vent flow rates when using PPV. Only cold flows were used.

The study described in [15] found that flow rates measured through the exit vents were significantly lower than the rated flow rates of the fans and that there were clear differences between different fan flows with nominally same power rating. Therefore, factors other than motor rating should be considered when selecting fans for use in positive pressure ventilation.

It was also found that exhaust flow rate increases with increasing distance between fan and inlet but decreases as volume of the structure increases. Further, increasing the exhaust area decreases the flow loss, thus increasing the efficiency of positive pressure ventilation.

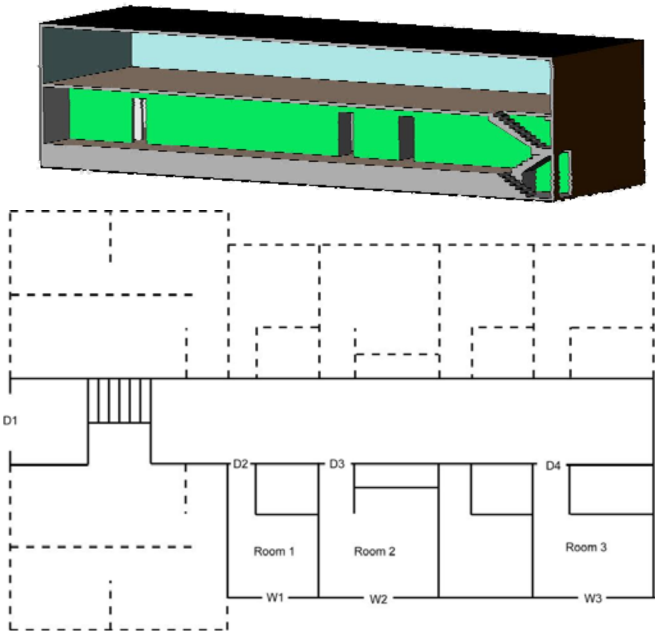

Figure 6: The layout of the experiments described in [15].

SUPPRESSION

Considerable experimental and theoretical work on fire suppression has been carried out by staff at the fire fighter training facility in Revinge, Sweden [16, 17, 18, 19, 20, 21]. In [16] some experimental work is described where the purpose was to compare a high-pressure (~40 bar) system with a normal pressure (~10 bar) system, where the systems are mounted on a fire engine. The fuel was particle board applied on the walls and ceiling of a 12m long, 5m wide and 2.5m high fire fighter training facility. Fifteen tests were carried out, temperatures measured and water applied using a manually oscillated nozzle from a fixed position within the room. One normal-pressure nozzle and two high-pressure nozzles where tested.

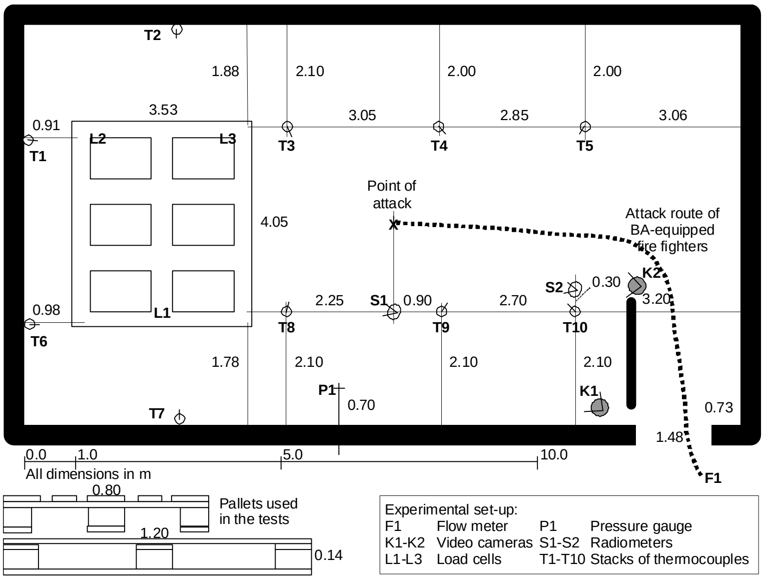

Figure 7: The test facility described in [17].

In [17], a larger test facility was used with the purpose of investigating the capacity of the fire service to fight fires in large spaces and obtain data with the purpose of quantifying this capacity. High-pressure was compared with a low-pressure fire fighting system and the heat stress on BA-equipped fire fighters during fire attack was measured. Six tests were performed in a room measuring 14.0 × 7.7 m², 6.3 m in height, with 0.4 m thick walls of concrete. The fuel consisted of standard wood pallets arranged in 6 stacks with 13 pallet in each stack. Figure 7 shows an outline of the facility.

Results from the tests reported in [16] and [17] showed that a rigid hose used together with a high-pressure system generally decreases the attack time and reduces the temperature more than low-pressure water sprays, especially when applying water oscillating from a fixed position within the room. The high-pressure system has a better extinguishing effect regarding gas phase extinction. When both surface cooling effects and gas phase effects are considered, the high-pressure system requires only approximately two-thirds of the water required by the low-pressure system to achieve the same extinction capacity in this scenario.

The increase in pulse rate of the fire fighters appeared to be triggered by mental stress and increased due to increasing skin temperature. Working conditions for fire fighters may become unbearable due to heat stress, even when the workload is low.

Further experimental and theoretical work on suppression is reported in [19] and [20], where the latter gives a comprehensive scientific overview of fire suppression. As a result of that work a text book for fire fighters on suppression, aimed for training and education, was published [21].

TACTICS

Fire fighting tactics can be defined as the efficient use of resources during a fire and rescue operation. The fire service has a number of procedures to accomplish goals during such operations, with the use of available resources.

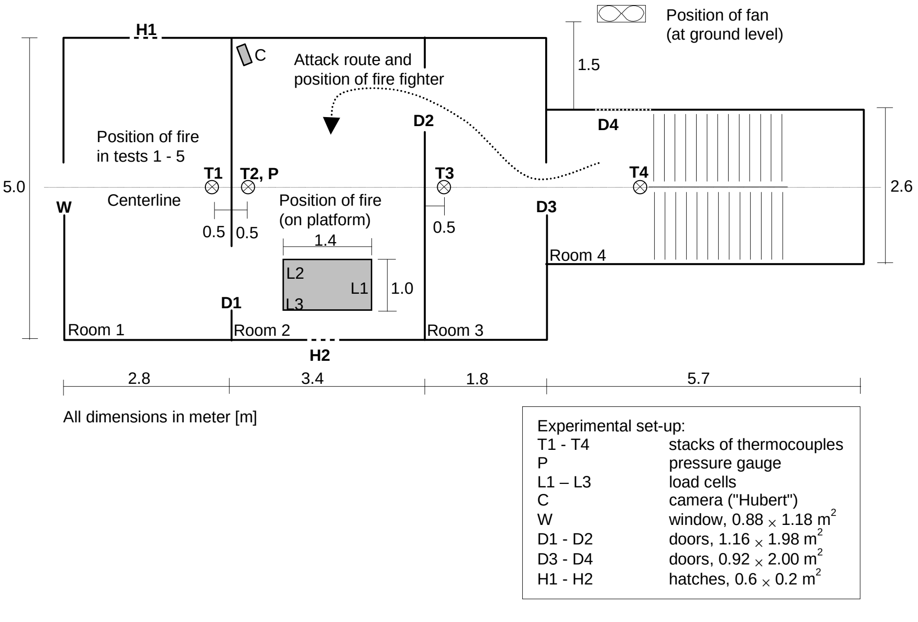

Figure 8: Experimental set-up in the first experimental series [22].

In order to investigate fire fighting tactics, a number of experiments have been performed [22], [23], [24]. The experiments included manual fire fighting using various suppression techniques (varying nozzle pressure and flow rates), positive pressure ventilation and the use of various openings for ventilation. Basically, the purpose of the experiments was to investigate various tactical patterns used during fire fighting operations, and to identify and verify a few basic tactical principles. Here, tactical patterns were defined as a set of procedures initiated, coordinated and carried out during a fire fighting operation.

In the first experimental series 20 tests were performed in a three-room apartment, on the first floor of a three-storey apartment building with an attached staircase, see Figure 8 [22].

In the second experimental series, 9 tests were performed in a small mechanical workshop, with the workshop on the ground floor and a small office on the first floor, see Figure 9 [23].

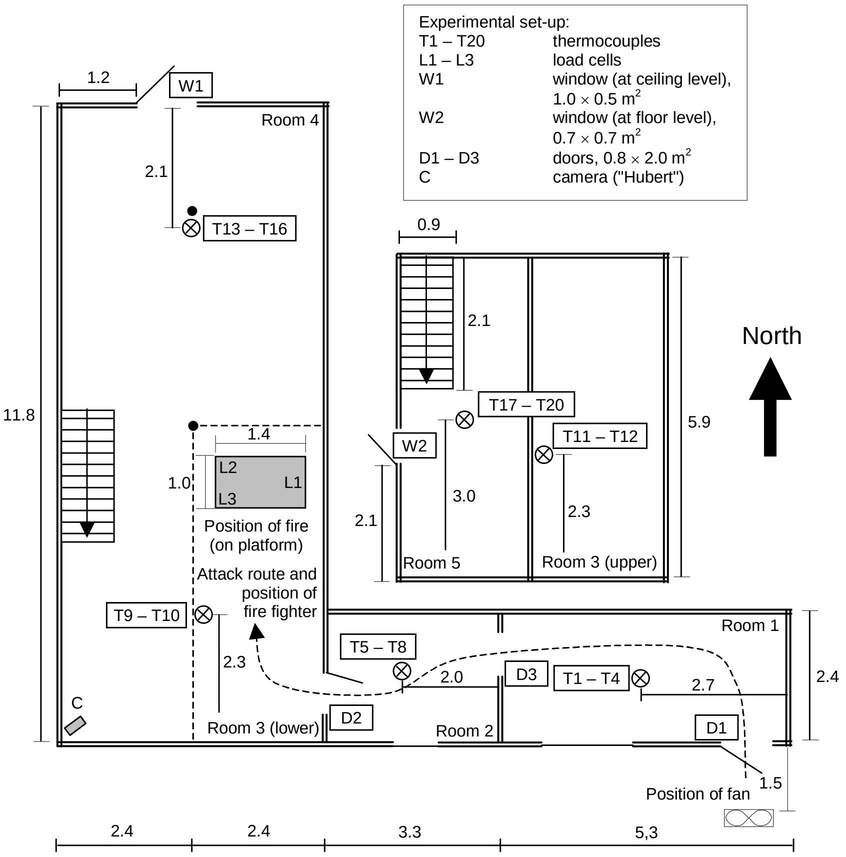

Figure 9: Experimental set-up in the second experimental set-up [23].

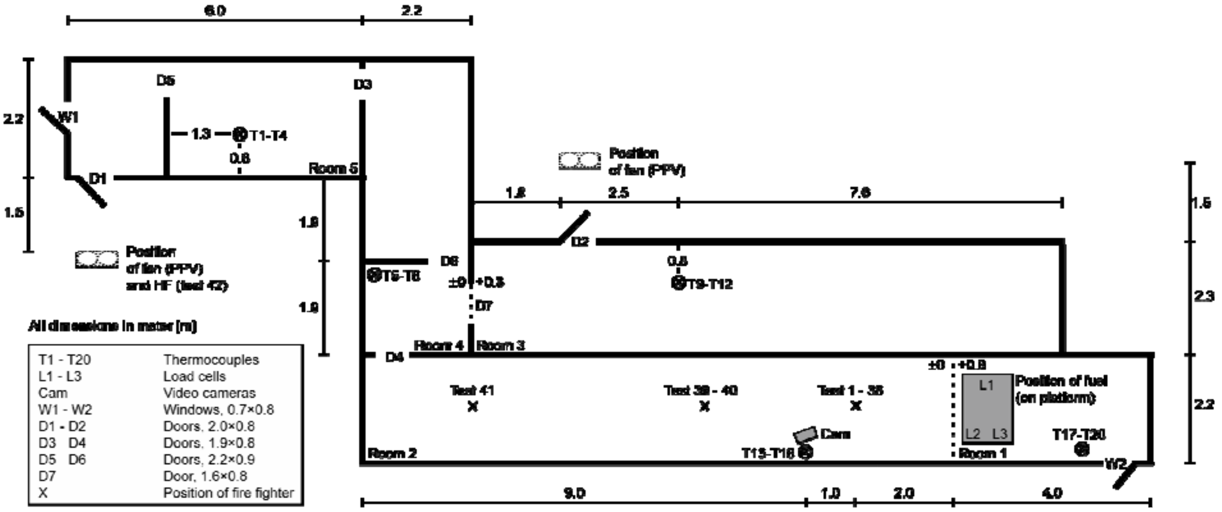

Figure 10: Experimental set-up in the third experimental series [24].

In the third experimental series, 44 tests were performed in a residential type, multi-room fire fighter training facility, see Figure 10 [24].

The experiments showed that various tactical patterns can be ranked in some measure of efficiency, based on reduction of temperature in various parts of the compartment. An example of this, taken from the first experimental series [22], is shown in Figure 11.

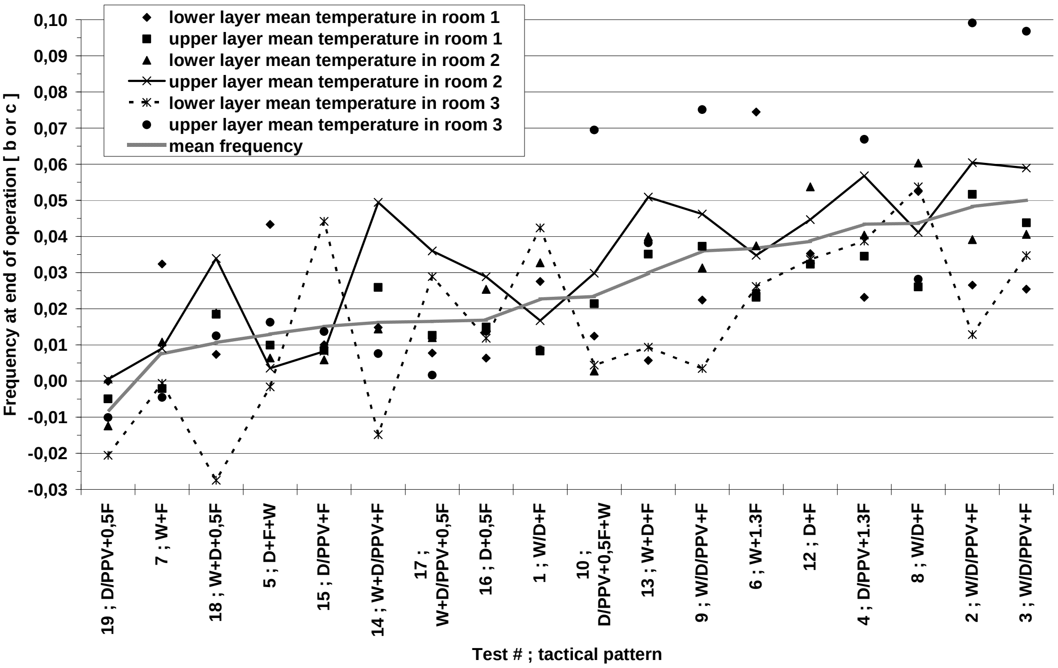

Figure 11: Efficiency of various tactical patterns. Notation includes opening of window (W), opening of door (D), use of positive pressure ventilation (PPV), full flow (F), half flow (0.5F) and 30% above full flow (1.3F). Slash ("/") indicates simultaneous onset of procedures, and a plus sign ("+") indicates additional procedure or procedures taken at time steps t = t1 and at time step t = t2 [22].

Based on such ranking of efficiency, basic tactical principles were established. These basic tactical principles includes [25], [29]

- the outcome of a fire fighting operation is dependent on the individual procedures as well as on their sequence of implementation
- the choice of tactical pattern is dependent on the situation as well as on the objectives of the fire fighting operation
- various procedures initiated on the fire ground must be coordinated, i.e. command and control of fire fighting operations is vital
- the choice of tactical patterns may be of a greater importance to the outcome of an operation than the outcome of a single procedure itself
- certain tactical patterns have an inherent indulgence towards defective or inappropriate procedures
- defective or inappropriate procedures or tactical patterns can be corrected during a fire fighting operation
- an objective may change during a fire fighting operation and different objectives during an operation may influence what tactical patterns are considered as “correct” and what are considered as “incorrect”
- when looking at effectiveness of fire fighting operations, work and work performance during an operation must be addressed.

In a wider perspective, the experiments constitute a basis for further handling of command and control problems.

CONCLUSIONS: TEACHING MATERIAL PRODUCED FOR THE FIRE SERVICE

During the last decades rapid development within modern building technology has resulted in unconventional structures and design solutions; the physical size of buildings is continually increasing; there is a tendency to build large underground car parks, warehouses and shopping complexes. Industrial installations are increasing in size and complexity. The interior design of many buildings with large light shafts, patios and covered atriums inside buildings, connected to horizontal corridors or malls, introduces new risk factors concerning spread of smoke and fire. In many practical circumstances, past experiences or historical precedents on how to deal with fire hazards in new or unusual buildings are not available.

At the same time there has been a rapid progress in the understanding of fire processes and their interaction with humans and buildings. Advancement has been particularly rapid where analytical fire modeling is concerned. Several different types of such models, with a varying degree of sophistication, have been developed in recent years and are used by engineers in the design process and by experimentalists when simulating fire development and the response of fire fighters. Great progress has also been made in experimental measurements and visualization of experimental data.

The need to take advantage of the new emerging technology, with regard to fire fighting, is obvious. The increased complexity of the technological solutions, however, requires higher levels of training for fire fighters and a higher level of continuing education during their carriers. High quality teaching material is needed for this purpose.

Much of the work quoted in this paper has been performed by workers who have a background as post-graduates at the Department of Fire Safety Engineering and Systems Safety at Lund University and have subsequently gained work experience in the fire service or at training facilities for fire fighters. The work has grown through licentiate or doctorate theses, with a solid scientific base, through experimental work carried out to benefit the fire service which has been introduced in scientific journals and symposia. This has finally resulted in a number of textbooks on various subjects being published where the main focus groups are fire fighters and fire officers. And although the mathematics and the fundamental physics and chemistry are not explicitly expressed in the text, the solid scientific base is there. The textbooks have been published by the Swedish Civil Contingencies Agency and some of them have been translated into English, for example [6], [21], [27] and [28].

The authors of this paper strongly believe in the importance of facilitating rapid transfer of technology from fire science to the fire service by producing relevant and appropriate teaching material with a sound scientific basis.

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