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A NEW GENERATION OF LARGE SCALE FIRE TEST METHODS

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ABSTRACT

This report summarizes research and development activities on large scale fire test methods based on oxygen consumption calorimetry carried out at the Swedish National Testing Institute during the latest decade.

The work towards a standardized NORDTEST method as well as an international standard for measuring and characterizing burning behaviour of surface materials is described.

The developed classification philosophy and the proposed criteria for assessing surface products based on the NORDTEST method is discussed.

The application of oxygen consumption calorimetry for testing full size upholstered furniture is also presented.

Finally, the implications on this research to European harmonization of testing and classification is discussed.

Key words: fire, large scale tests, oxygen consumption calorimetry

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TABLE OF CONTENTS

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PREFACE

This report forms a licentiate thesis together with the following works:

Sundström, B., Wickström, U., "Fire: Full-Scale Tests, Background and Test Arrangements. Nordtest Project 143-78", Technical Report SP-RAPP 1980:14, Borås 1980.

Sundström, B., Wickström, U., "Fire: Full-Scale Tests Calibration of Test Room - Part 1. Nordtest Project 143-78, 2", Technical Report SP-RAPP 1981:48, Borås 1981.

Sundström, B., "Full-Scale Fire Testing of Surface Materials. Measurements of Heat Release and Productions of Smoke and Gas Species", Technical Report SP-RAPP 1986:45, Borås 1986.

Sundström, B., Kaiser, I., Wickström, U., "Corner Test - Zur Einschätzung des Brandrisikos von Innenbekleidungen in Räumen", Supplement 4-87 Materialprüfung, Git Verlag.

Sundström, B., Göransson, U., "Possible Classification Criteria and their Implications for Surface Materials Tested in Full-Scale According to ISO/DP 9705 (NT FIRE 025)", Technical Report SP-RAPP 1988:19, Borås 1988.

Sundström, B., "Full-Scale Fire Testing of Upholstered Furniture and the Use of Test Data", New Technology to Reduce Fire Losses and Costs (Grayson and Smith, Ed) Elsevier applied science Publishers, 1986.

1 THE NEED FOR LARGE SCALE TEST METHODS FOR MEASURING BURNING BEHAVIOUR

1.1 The problem of Assessing Products Behaviour in a Fire

Fire is a very complex phenomenon. The behaviour of a certain product in a certain fire situation depends on a variety of factors.

The most significant factor is the material compound which the product is made of. In fact, many fire test methods are based on the idea that universal material properties are measured and could serve as a sole ground for characterizing products. Unfortunately that is not the case. The same material can form different products of strongly varying fire properties, e.g. foamed or non-foamed plastics, porous wood fibre board or particle board. In this case the variation in density, which influences the thermal properties, has a profound effect on ignition and flame spread properties. The porous wood fibre board for example spreads fire considerably faster than a particle board.

Then the geometrical shape will play a role. A wooden crib is easier to ignite and will burn more intensely than a log of the same mass.

The location and use of a product in a building poses another problem. The same material appearing as a floor covering or alternatively as a large curtain will give rise to quite different behaviours in a room fire. The curtain may exhibit easy ignition and fast flame spread over a large area. The floor covering, on the other hand, may not burn until the fire is very large.

The type and size of ignition source have a significant effect. For instance some flame retardant treated thermoplastics may never ignite for a laboratory size flame due to melting. In a full scale situation, however, a larger area is exposed to heat and a very intense and fast fire spread may occur.

Then there are effects of room size, boundary conditions and air supply. These factors influence the transition of a localized fire into a fully developed fire. i.e. flash-over.

The list of factors of importance for the onset and development of a fire can be made long and is to a large extent not known. Mathematical modelling of fires will provide for the long term solution as discussed in [1]. In the absence of this tool the true way to assess product behaviour would therefore be to make real fires of the situations of interest. This is not feasable. Therefore large scale assessments of representative scenarios must be carried out instead.

Thus it was early recognized that small scale laboratory tests were improper for testing for example thermoplastics, highly insulating substrates and joints. However, instead of making a large scale evaluation, sometimes undesirable small scale testing solutions were employed. One way was to state that the product was unclassifiable (as the method did a bad job). Another was to find a sample preparation procedure that allowed testing regardless of link to reality. This can of course not hold in the long run and a concern was growing among fire safety engineering experts.

1.2 Large Scale Tests are Links to Real Fires

In Sweden, Fire Technology at the Swedish National Testing Institute (SP) addressed this problem in a pragmatic way already in the 50's. When the bench scale test, (the Swedish hot box [2]) gave doubtful results a large scale two room building test was used [3]. The product behaviour was then assessed by visual observations. The system works very well, although a quantitative measure is lacking as a basis for the classification.

In the early 80's, the oxygen consumption calorimetry became available as a possible way of achieving quantitative values of room fires. SP realized the importance of this and started development work at a very early stage which lead to a new generation of versatile large scale fire test methods. Now these methods can be seen as candidate methods for European harmonization for testing and classification. This report describes the work up to that point.

2 SURFACE LININGS IN A SMALL ROOM. HEAT RELEASE RATE AND OTHER FIRE PARAMETERS - FIVE REPORTS

To appraise a product a measure of fire growth and smoke production versus time is needed. The heat release rate is the most important measure of fire growth. Consequently the heat balance in a fire room was studied.

2.1 Thermal Measurements and Heat Balance. Sundström, Wickström, 1980 and 1981

The reports "Fire: Full Scale Tests. Background and Test Arrangements" and "Fire: Full Scale Tests. Calibration of Test Room - Part 1" give full sets of data for the heat balance in a small room exposed to two levels of steady state heat release rate from a gas burner. The test room was made from light weight concrete and was having the dimensions 2.4 m x 3.6 m x 2.4 m (L x W x H). An open doorway (0.8 m x 2.0 m) was located at one of the short sides. The entire set up was the first of its kind in Europe.

The heat balance in the fire room was estimated by measuring the quantities in the following equation.

$$\dot{Q}_c = \dot{Q}_o + \dot{Q}_w + \dot{Q}_r$$

where $\dot{Q}_c$ is the heat released by fuel combustion, $\dot{Q}_o$ is the heat lost by convection through the doorway, $\dot{Q}_w$ is the heat lost by conduction into the surrounding structure and $\dot{Q}_r$ is the heat lost by radiation through the doorway.

As quasi steady-state conditions were studied other terms in the heat balance was neglected, i.e. the increase of heat stored in the gas volume inside the compartment.

$\dot{Q}_c$ was given by measuring the fuel consumption. The experiments were made on two energy levels of 125 kW and 250 kW.

$\dot{Q}_o$ was arrived at by measuring mass flow rate and temperature out the doorway at a number of locations, calculating the position of the neutral layer and then integrating. The mass flow rate was calculated from measurement of the temperature and the pressure differential over a pitot tube type probe.

$\dot{Q}_w$ was calculated from measurements of the temperature gradient inside the surrounding structure.

$\dot{Q}_r$ was determined from surface temperature measurements of the structure. Assuming an emission coefficient and taking account of view factors the radiation through the doorway was calculated.

The components of the heat balance was measured with good agreement, see table 1. It did, however, require some 64 measuring points in the doorway and great care in positioning the probes. Also the measuring instruments, for example for pressure had to be of supreme quality.

Table 1 Heat balance of the fire room at optimum measuring conditions. Numbers in brackets are heat loss terms normalized to the heat released by the burner $\dot{Q}_c$. $\sum \dot{Q} = \dot{Q}_o + \dot{Q}_w + \dot{Q}_r$. Sundström, Wickström, 1981.

$\dot{Q}_c$ (kW)	$\dot{Q}_o$ (kW)	$\dot{Q}_w$ (kW)	$\dot{Q}_r$ (kW)	$\sum\dot{Q}$ (kW)
125	104 (0.83)	19 (0.15)	6 (0.05)	129 (1.03)
250	208 (0.83)	32 (0.13)	12 (0.05)	252 (1.01)

This comprehensive set of data was also tested against the equations for the two-zone models available at that time. The discharge coefficient, plume entrainment coefficient [4] etc were also calculated for this case. The main finding was, however, that there were not two discrete zones which the models were based on. The temperature profiles in the doorway showed a gradual increase over a rather long vertical distance. One of the reasons was a rising wall plume inside the burn room entering into the lower region of the hot zone. This was shown by measuring zero carbon dioxide in the lower part of the outflow. The heating of the walls at steady-state conditions was the reason for this wall plume.

Summarizing those works two main points were highlighted.

- A thermal method for measuring heat release in short and transient classification tests is unsuitable due to the complexity and inaccuracy of the measurements.

- Calculation support from two-zone models would not improve the situation considerably.

2.2 Oxygen Consumption Calorimetry and the Development of a Large Scale Test Method; the Room/Corner Test. Sundström, 1986

Different materials have widely different calorific heat content. However, if the energy released per unit of oxygen consumed in the combustion process is calculated almost a constant value appears. The value is about 17 MJ/m^3 for most building products. This fact was known since many years, but its implications for fire testing was not pointed out until 1980 by Huggett [5]. Parker [6] then gave calculation equations for open systems where the combustion gases were collected in a hood.

SP-Fire Technology was together with NIST (National Institute of Standards and Technology) in USA the first in the world to start development work of a large scale test method based on these principles [7]. Large efforts in developing the measuring technology was required. A valid measure of the oxygen consumed by the fire in the room had to be established. The combustion gases from the fire room was collected in a large hood connected to an exhaust duct. The basic design was taken from proposals within ASTM (American Society for Testing and Materials). The measurements were made in the exhaust duct where the flow profile was expected to be fully developed. An even flow was established by modifications in hood and exhaust duct. The paramagnetic oxygen analyser was deemed to bo the best type of instrument, the time delay in measurements was minimized, required instrument accuracy was identified and so on. The accuracy of the measurement with the final design was estimated to be about 10 %.

The ignition source was a gas burner positioned in a corner. The size and heat output was developed at SP. The object was to have an ignition source allowing for testing as large a variety of building products as possible; wall and ceiling ignition was deemed important as well as a heat output that allowed measurement on very low to very high performance levels of products. A burner beeing 170 mm square and given a heat output of 100 kW for 10 minutes and 300 kW for another 10 minutes was found to be the most suitable. The test configuration was with the products on the to walls and on the ceiling.

The development work resulted in a test method description [8] which became a NORDTEST method, NT FIRE 025. It also influenced international standardization. NT FIRE 025 together with the corresponding ASTM-procedure [9], is now recognized as ISO DP 9705. The test set up is shown in figure 1.

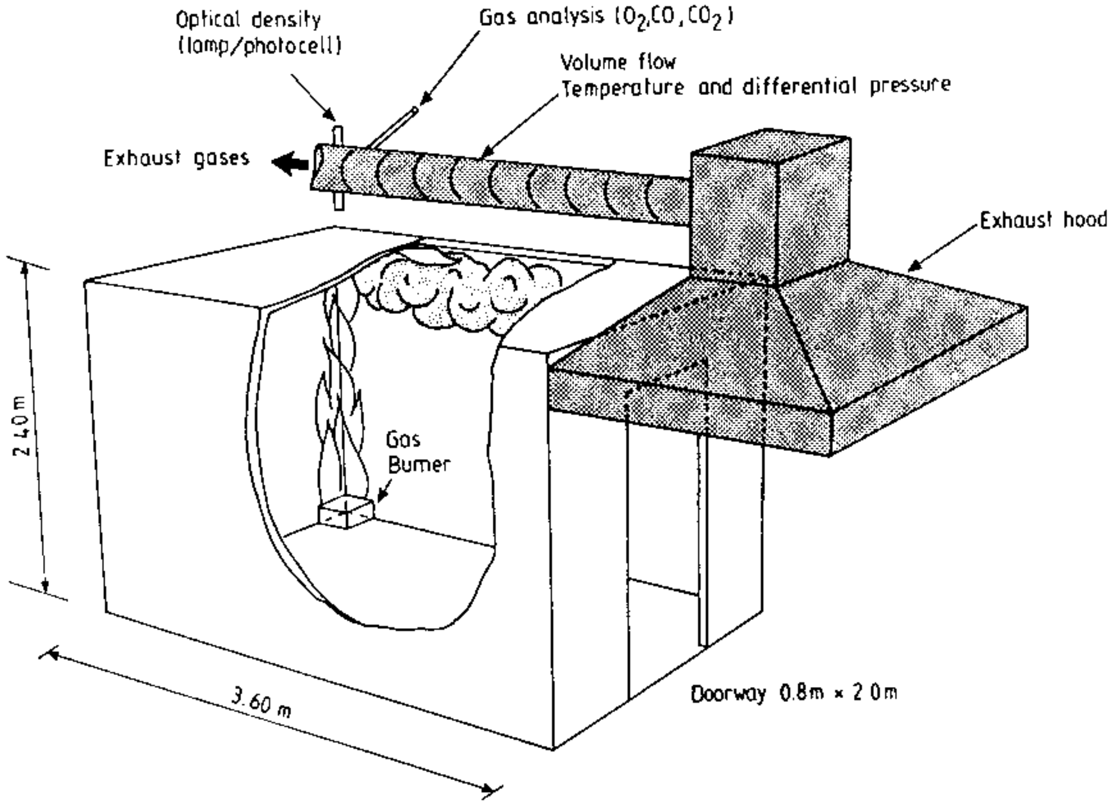

Figure 1 The Room/Corner Test. NT FIRE 025 and ISO DP 9705. A test method for evaluation of surface lining products.

In "Full Scale Fire Testing of Surface Materials, Measurements of Heat Release and Productions of Smoke and Gas Species" a detailed mapping of the charateristics of 18 room fires with 13 products is published. The test procedure was according to NT FIRE 025. Additional measurements of temperatures of gas, room structure and specimen surface as well as of convective heat flow rate through the doorway, heat fluxes and toxic gas species were made.

The conditions at or just prior to flash-over were especially studied with the object of identifying the most important parameters for fire safety performance.

Firstly the definition of flash-over was investigated. It was found that the minimum heat release rate required to cause flames to emerge out the doorway was about 1 000 kW. However, the fast burning products showed as much as 6 000 kW at the instant of flaming through the doorway. A value of 20 kW/m^2 irradiance at the floor was also reported in litterature as a flash-over criterion [9]. The measurements showed 10 - 50 kW/m^2. Anyhow all values were rising very rapidly with time and flash-over time did rarely vary by more than 10 seconds regardless of any of the above mentioned definitions.

Another important observation was that the production of carbon monoxide and total hydrocarbon was a function of burning rate. Close to flash-over when the fire became affected by limited ventilation the values rised dramatically to about 2 % of CO in the gas stream leaving the room regardless of type of product. This content is highly toxic.

The smoke production was also found to be dependent on burning rate. Product properties could, however, be identified as the smoke yield values varied by a factor of ten depending of product.

Finally it was apparent that the ignition source and the test configuration choosen allowed for valid measurements of fire behaviour on products ranging from nearly non-combustible to extremly flammable.

2.3 A Classification System for Surface Products. Sundström, Kaiser, Wickström, 1987. Sundström, Göransson, 1988

Any classification system must have some basic qualifications in order to be acceptable for wide use.

- It has to reflect fire safety levels that are easily understood by non-experts and known to be justified.
- Authorities should have an option in choosing the appropriate performance level for their needs.
- The system should be fair for all types of products.
- Tests must be easy to perform, be reproducible and not too expensive.

Looking at the existing test methods and classification criteria around in Europe today reveals drawbacks on all the above points except maybe the last one.

In the works "Corner Test - zur Einschätzung des Brandrisikos von Innenbekleidungen in Räumen" and "Possible Fire Classification Criteria and their Implications for Surface Materials Tested in Full Scale According to ISO DP 9705 or NT FIRE 025" a new classification system is proposed based on an argumentation covering these basic principles.

The most important parameters for classification are identified in the reports as the heat release and smoke production rates. The heat release rate is a measure of fire size and can in a room fire be used to define flash-over. Smoke can move long distances in a building and constitute a hazard far away from the fire. Thus the production rate is related to possibility of escape.

The measured heat and smoke rates are used to form a proposal for classification of surface products based on their performance in the large scale test. The Room/Corner Test is then assumed to be representative of real fires. The choosen heat release criteria are linked to time to flash-over in the room and the smoke criteria are choosen with reference to wood. Thus the system reflects fire safety levels that are easily understood. The proposed classes are reproduced in table 2.

Table 2 The proposed classification criteria for surface products when tested in the Room/Corner Test. Sundström, Göransson, 1988.

Class	Minimum time	Heat release rate			Smoke production rate	
		(burner excl) peak	(burner incl) peak	(burner excl) average	peak	average
	(min)	(kW)	(kW)	(kW)	(obm^3/s)	(obm^3/s)
A	20	300	600	50	10	3
B	20	700	1 000	100	70	5
C	12	700	1 000	100	70	5
D	10	900	1 000	100	70	5
E	2	900	1 000	-	70	-

Five classes are proposed giving the option of choosing between levels. So is for example class A rather like the German A2 while Nordic class 1 is a mixture of classes A and B. For further details, see Sundström, Göransson 1988.

By using large scale performance as a basis, equal and fair treatment of all types of products is greatly emphasized. It is, however, expensive and time consuming to always do large scale tests and therefore a shortcut is needed. Such a route is beeing proposed by Wickström and Göransson [10] who have developed a calculation model that can predict the large scale room fire behaviour based on test data from the Cone Calorimeter, a bench scale size test. It has been proven to be very successful and could provide for the cheep and easy testing that is needed for a good classification system. Flame spread modelling based on data from two small scale tests [11], [12] as well as correlation studies with the Cone Calorimeter [13] have also been succesful in establishing a link between the bench and the large scale test results.

At the moment work is going to further refine and support the classification proposal [14]. Co-operation has started at the European level and the proposal is seen as a candidate for ultimate European harmonization for classifying surface products.

3 UPHOLSTERED FURNITURE. ANOTHER APPLICATION OF THE NEW TECHNOLOGY. SUNDSTRÖM, 1986.

Once it was demonstrated that a room fire test procedure based on oxygen consumption calorimetry could be used for routine testing of surface products other applications were apparent.

Upholstered furniture, recognized as a major fire hazard, was a natural choice for a burning behaviour test.

In the work "Full-Scale Fire Testing of Upholstered Furniture and the Use of Test Data" (see also [15] and [16]) a test procedure as well as aspects of test data are discussed.

The test comprises a full size sofa mock-up or an actual sofa sample allowed to burn with no restrictions of air supply, see figure 2. The oxygen consumption technique is used to measure the heat release rate; smoke production and toxic gas species are also measured. New is the measurement of mass loss rate accomplished by positioning the sample on load cells. The ignition source is a British wooden crib for furniture testing. The test was developed to a NORDTEST method, NT FIRE 032 [17]. Slightly modified, it is also considered for use in the UK.

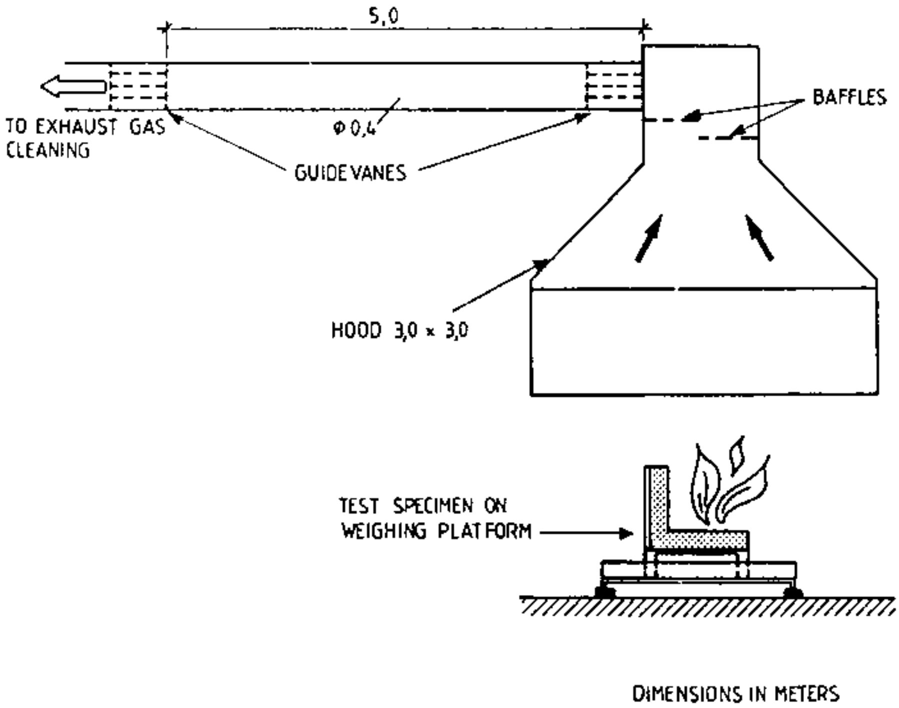

Figure 2 Application of the oxygen consumption technique to test sofas.

The versatility of this test is demonstrated by simple examples of "back-of-an-envelope" calculations. Risk of flash-over, ignition of second item, smoke filling etc can be estimated. The effective heat of combustion can be calculated by combining the rates of heat release and mass loss. The best use of this test, however, is to use the results as input in room fire models like FAST or DSLAY V.

Other researches at SP also applied oxygen consumption calorimetry for test methods. Göransson, Wetterlund and Persson developed NORDTEST methods for pipe insulation, Fluid Sprays and large free hanging curtains [18], [19], [20].

4 EUROPEAN TESTING AND CLASSIFICATION. AN OUTLOOK

Europe shall harmonize fire testing and classification before the end of 1992. The modern test methods based on oxygen consumption calorimetry are available for this. As earlier described the bench scale Cone Calorimeter and the Room/Corner Test can constitute the test methods on which a European classification procedure is based.

Sweden, and the other Nordic countries, are proposing such a methodology to the European standardization organization, CEN. The classification criteria as given in table 2 are put forward. To further base the proposal a comprehensive Nordic R & D programme, EUREFIC [14], is being performed. Co-operation has also started with laboratories in the UK, Germany and Italy. Many European laboratories are supplying themselves with the new tests and gaining experience.

The question now is how an interim solution based on the old European tests can be applied for a short period of time until everybody involved feels confident with the new technology and all details are worked out.

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