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Birgit Östman

Results of Scandinavian Tests and Research on Reaction to Fire

Paper Presented at the Eurowood Oxford Fire Conference, July 1993

Trätek

INSTITUTET FÖR TRÄTEKNISK FORSKNING

Birgit Östman

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FOREWORD

This paper was presented at the Oxford Fire Conference organised by Trada on behalf of Eurowood on July 1 and 2, 1993. It was distributed together with other papers presented to the delegates at the conference.

ABSTRACT

Two major research programs on reaction to fire of building products have been performed in Scandinavia during the last 10 to 15 years. The first one 'Fire hazard and compartment fire growth' started around 1980 as a cooperation between three Swedish laboratories and was led by professor Ove Pettersson, Lund. It was mainly focused on developing new experimental techniques and new theoretical methods to understand the early fire growth. Its aim was also to support the international standardization within ISO. The second program 'Eurefic' started in the late 80-ies as a cooperation between the four national fire laboratories in Denmark, Finland, Norway and Sweden. It was led by professor Ulf Wickström, SP and focused mainly on support to the development within the European Community and CEN.

Both programs have concentrated on surface linings and on heat release during fire. New techniques based on oxygen consumption as the cone calorimeter and the room fire test have been studied and utilized. Different models which predict the full-scale behaviour from small-scale data have been developed. These models clearly show that the new technique is superior to the present national standards and thus supplies new possibilities.

Some recent data show that flame retardants have a marked effect on the fire behaviour of wood products also according to the new test methods which has been questioned earlier.

The conclusions are that the new technology is ready for European standardization but experience is still lacking in some countries. For wood it is important to reach a fair classification in relation to other products. A classification system with three to four classes for surface linings is suggested. Smoke production should be included.

The wood industry should also put more emphasis on fire issues as other industries do. Regulators should be more aware of the possibilities to use the new techniques to achieve fire safety and facilitate free trade in Europe.

SAMMANFATTNING - SWEDISH SUMMARY

Brandens tidiga skede är avgörande för personsäkerheten vid utrymning av ett rum, en lägenhet eller en byggnad. Byggnadsmaterialens och - i ännu högre grad - inredningsmaterialens medverkan och beteende är därvid utslagsgivande. Kunskapen inom området har länge varit bristfällig och mer begränsad än för den fullt utvecklade branden. Detta har bl a lett till att föråldrad metodik, som inte kan användas för många nya produkter, fortfarande används i nationell lagstiftning i Europa.

Det har därför varit en angelägen uppgift att ta fram ny kunskap och att utveckla experimentella och teoretiska metoder som förbättrar möjligheterna att förutsäga det tidiga brandförloppet och bedöma risker i olika brandmiljöer. Därmed kan också tekniska handelshinder undanröjas.

Sverige och Norden i övrigt bedriver internationellt uppmärksammad forskning inom området. Två större forskningsprogram har genomförts sedan början av 80-talet. Det första 'Brandrisker i det tidiga brandförloppet' var ett samarbete mellan Lunds tekniska högskola (LTH), Statens provningsanstalt (SP) och STFI (nuvarande Trätek). Det stöddes finansiellt av Brandforsk och leddes av professor Ove Pettersson, Lund. Arbetet inriktades i hög grad på att ta fram vetenskapligt underlag som stöd för internationell standardisering inom ISO. Det andra programmet 'Eurefic' var ett samarbete huvudsakligen mellan de officiella provningslaboratorierna i Danmark, Finland, Norge och Sverige. Det stöddes bl a av Nordtest, Nordisk industrifond och industrin och leddes av professor Ulf Wickström, SP. Arbetet inriktades i hög grad på att ta fram underlag för europeisk standardisering inom CEN.

Båda programmen har koncentrerats till ytmaterial på väggar och i tak. Ny provningsteknik som bygger på mätning av värmeutveckling under brand finns nu tillgänglig både i liten skala i form av den s k konkalorimetern och i full skala i form av rumsbrandprovning. Båda metoderna har nyligen standardiserats internationellt som ISO 5660 resp ISO 9705. Avsikten är att småskalig provning skall kunna användas i flertalet fall och genom modeller kunna förutsäga beteendet vid fullskalig rumsbrand. Flera olika sådana modeller har utvecklats bl a vid LTH, SP och Trätek. Samtliga modeller visar klart att den nya småskaliga tekniken kan förutsäga åtminstone ett fullskalescenario, rumsbrand, och därmed är överlägsen nuvarande nationell standard.

Den nya metodiken har haft svårigheter att få genomslag i europeisk standardisering. Orsakerna är flera. Många länder saknar egen erfarenhet och vill därför behålla kända system. Många företag t ex inom plastindustrin har dessutom utvecklat produkter som f n är konkurrenskraftiga och vill därför inte byta system.

En ny klassificering av ytmaterial i fem (eller egentligen sex) klasser baserad på rumsbrandprovning har föreslagits inom Eurefic. Detta förslag är alltför finindelat och överskattar ytmaterialens inverkan på det tidiga brandförloppet. Träprodukter hamnar dessutom i sämsta klassen, vilket inte är rättvisande eftersom det finns produkter med betydligt större risk för övertändning. En indelning i tre eller fyra klasser vore mera naturlig.

Några nya data presenteras också som visar att flamskyddsmedel har en markant effekt på träprodukters brandbeteende även enligt den nya provningstekniken. Detta har tidigare ifrågasatts bl a från England och Tyskland, där man använder mer flamskyddsbehandlade produkter än i Sverige.

Slutsatsen är att den nya tekniken är färdig för europeisk standardisering, men ytterligare insatser krävs för kunskapsspridning till länder med liten erfarenhet inom området. För trä är det viktigt att ett nytt klassificeringssystem blir rättvisande i relation till andra material. Dessutom bör rökutveckling ingå i klassificeringen eftersom vissa produkter utvecklar stor mängd rök även om de inte bidrar till övertändning. Träprodukter har i allmänhet måttlig rökutveckling.

Träindustrin och dess organisationer bör vara mer aktiva i brandfrågor. Andra industribranscher t ex plastindustrin har varit långt mer aktiva. Lagstiftare bör bli mer uppmärksamma på den nya teknikens möjligheter att förbättra brandsäkerheten och underlätta handelsutbytet i Europa.

Results of Scandinavian Tests and Research on Reaction to Fire

Birgit Östman
Trätek - Swedish Institute for Wood Technology Research

INTRODUCTION

The early fire growth is decisive for the safety of life at evacuation of a room, a flat or a building. The contribution of interior surface materials might be substantial and is harder to predict or model than the fully developed fire. It is therefore important to develop new knowledge and tools in order to create a more realistic and performance based classification system than the present national standards can supply.

Furniture, interior fitting and other building content will also contribute to the fire growth, in many cases more than the surface linings, but is presently not so strictly controlled by legislation and is not included in this paper.

Much work in the field has been carried out around the world, maybe especially in Northern America and Japan. The Scandinavian work has tried to keep in touch with the international development and form a complementary part to those major contributions. This paper will be limited to the Scandinavian research.

A first analysis on the research needs was presented in the late 70-ties /22/. It resulted in a major research program in Sweden, Fire hazard and compartment fire growth, later followed by the Eurefic (European reaction-to-fire classification). Both programs have focused on developing new technologies and a better understanding of the fire growth process. They have also been closely linked to the international standardization within ISO and CEN. A brief summary of the programs will be presented with some emphasis on wood products.

RESEARCH PROGRAMS

1. Fire hazard and compartment fire growth

The first program started in 1980 in Sweden /23/. Its goal was to develop and evaluate tests and models to predict fire hazards in the early fire growth process in a room. It was a cooperation between the Lund University, the Swedish National Testing Institute, SP, and the Swedish Forest Products Research Laboratory, STFI (1984 divided and changed to Swedish Institute for Wood Technology Research, Trätek). The program was led by professor Ove Pettersson, Lund University and sponsored by the Swedish Fire Research Board, Brandforsk. It has resulted in about 100 reports /2/.

Small-scale tests focused on rate of heat release, but other tests were also evaluated including ignitability, surface spread of flame, smoke production and toxicity. Full-scale experiments included both surface linings and furniture and has lead to a standard for the room fire test, Nordtest NT Fire 025. Models of different types were developed. A large data base was created and includes experimental data for 13 different surface linings from:

- room fire test
- model room test (1:3)
- rate of heat release tests (OSU, STFI, cone calorimeter)
- surface spread of flame tests (ISO, IMO)
- ignitability (ISO)
- smoke (NBS and cone calorimeter)
- national standard tests.

2. Eurefic program

The second program started in 1989 as a result of the development in Europe to find a harmonized solution on the reaction-to-fire of construction products. Its goal was to contribute to the development of future European fire test methods and classification. It was a joint activity mainly between the national fire laboratories in Denmark (Dantest), Finland (VTT), Norway (SINTEF NBL) and Sweden (SP). Other laboratories such as Lund University and Trätek carried out some supplementary work to the program which was led by professor Ulf Wickström, SP. The work was sponsored by Nordtest and several industries in the four countries.

The program was subdivided into 10 projects:

- Interlaboratory study of the cone calorimeter (ISO 5660).
- Interlaboratory study of the room corner test (NT Fire 025/ISO 9705).
- Tests in larger scale than NT Fire 025.
- Models for predicting the fire growth in the room corner test.
- Models for flame spread.
- Correlations with the Nordic fire test methods.
- Correlations with other European fire test methods.
- Preparation of a new classification system.
- Effects on products and building costs.

A set of 11 different surface linings was used and a data base on all experimental results is available. A summary report presents the main results /29/.

Other programs have also been performed. One example is an interlaboratory study of the room fire test in order to supply information for international standardization (ISO 9705). Four surface linings were tested at four laboratories in Denmark, Finland, Norway and Sweden. Additional data were collected from the cone calorimeter.

SMALL-SCALE RESULTS

Rate of heat release has been the main parameter studied. Early research at the Swedish Forest Products Research Laboratory, STFI, dealt with the development of experimental techniques /26/. It was found that tests based on oxygen consumption are superior to techniques based on temperature measurements. Different experimental approaches including the cone calorimeter gave similar results /16/ which is a strong indication of the basic nature of heat release in fires. Simultaneously, the cone calorimeter was adopted internationally. Contributions to its standardization were submitted and the national laboratories in all Scandinavian countries got the equipment earlier than in most other European countries.

The cone calorimeter has been widely used in the Scandinavian research. It provides basic data on several of the parameters which are important for modelling fire growth. Besides rate of heat release, data are obtained on ignitability, mass loss rate and smoke production. All data can be obtained at a range of heat flux levels up to about 100 kW/m^2, thus simulating also severe fire exposures. At the same time, the large amount of data obtainable from the cone calorimeter has confused many users.

The cone calorimeter has recently been adopted as an ISO standard (ISO 5660). The standardization was preceded by interlaboratory trials in which four Scandinavian fire laboratories participated.

Ignitability measured in the cone calorimeter can replace the ISO ignitability test which is obvious since the equipment is quite similar. Direct comparisons have been presented /12, 19/.

Smoke can also be measured in the cone calorimeter /20/ even if it is not included in the present version of ISO 5660. Successful interlaboratory trials have been performed /13/ with four Scandinavian laboratories participating. Smoke measurements will be included in the ongoing revision of ISO 5660.

Some typical data from the cone calorimeter are shown in Figure 1 and a summary of data of all 28 products tested in the Scandinavian programs are given in Table 1 /21/.

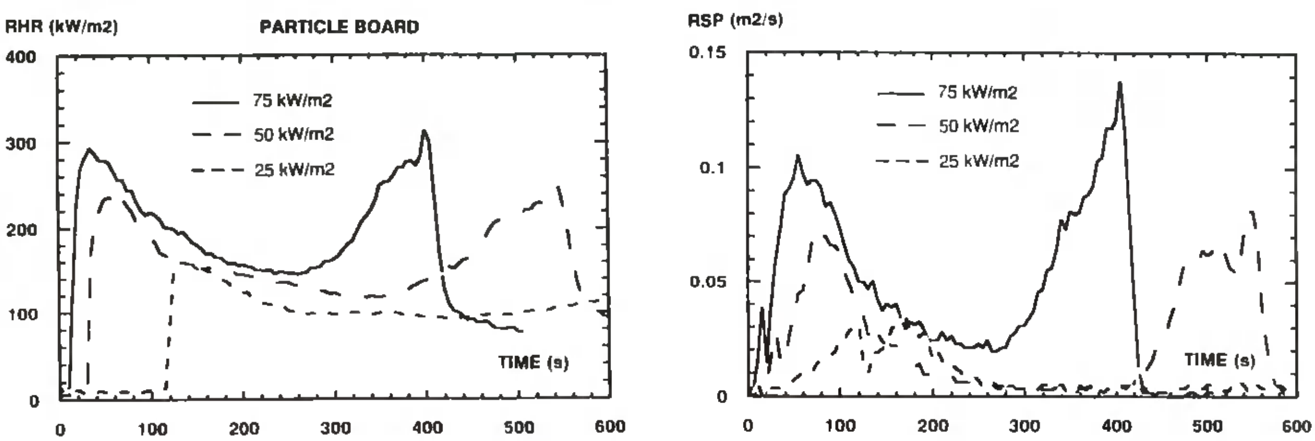

Figure 1. Some typical results from the cone calorimeter. Rate of heat release, RHR, and rate of smoke production, RSP, as a function of time at three heat flux levels 25, 50 and 75 kW/m².

Table 1. **Time to flashover in the room fire test** and **Cone calorimeter data** with retainer frame at 50 kW/m² and horizontal orientation.

Products	Room test Time to flashover	Cone Time to ignition	calorimeter THR$_{300}$[1)]	Mass[2)] loss$_{300}$
	min:s	s	MJ/m²	kg 10^{-3}
1. Painted gypsum paper plasterboard	> 20	47	7.0	10.7
2. Ordinary birch plywood	2:30	30	38.0	37.0
3. Textile wallcovering on gypsum paper plasterboard	11:00	25	12.8	14.8
4. Melamine-faced high-density non-combustible board	> 20	29	9.8	17.0
5. Plastic-faced steel sheet on mineral wool	> 20	53	3.7	1.9
6. FR particle board, type B1	10:30	21	10.4	18.7
7. Combustible-faced mineral wool	1:20	5	4.0	0.9
8. FR particle board	> 20	700	17.0	13.8
9. Plastic-faced steel sheet on polyurethane foam	3:15	19	17.2	14.2
10. PVC-wallcarpet on gypsum paper plasterboard	10:55	15	11.9	15.3
11. FR extruded polystyrene foam	1:20	31	22.3	7.8
12. Birch plywood	2:17	28	35.5	33.8
13. FR plywood	> 20	469	8.7	4.9
14. Melamine-faced particle board	3:02	34	32.9	23.0
15. FR polystyrene foam	1:07[3)]	25	24.2	6.8
16. Particle board	2:37	34	45.9	32.1
17. Insulating wood fiber board	0:59	12	33.2	22.3
18. Medium-density wood fiber board	2:11	31	32.6	31.5
19. Wood panel, spruce	2:11	20	25.0	25.1
20. Melamine-faced particle board	7:45	41	19.8	25.1
21. Plastic wallcovering on gypsum board	10:11	10	9.2	11.9
22. Textile wallcovering on gypsum board	10:29	20	12.1	14.7
23. Textile wallcovering on rockwool	0:43	11	8.5	4.6
24. Paper wallcovering on particle board	2:23	33	29.8	29.3
25. Rigid polyurethane foam	0:06	2	17.4	8.9
26. Expanded polystyrene	1:55	39	32.8	9.9
27. Paper wallcovering on gypsum board	10:40	21	9.4	10.5
28. Gypsum board	> 20	34	6.7	9.1

1) THR$_{300}$ = total heat release during 5 minutes after ignition (per 0.01 m² area).
2) Mass loss$_{300}$ = mass loss during 5 minutes after ignition.
3) One test reached flashover, but two others did not. Most unsafe case decisive.

Wood products generally exhibit a rather high rate of heat release after a time to ignition which is quite dependent on the heat flux level. The rate of smoke production is quite low compared to most other materials. Toxicity data are also fairly low /5/.

FULL-SCALE RESULTS

The room corner test for surface linings was developed and well specified by early research at the Swedish National Testing Institute, SP /24/. The work resulted in standardization as Nordtest NT Fire 025, which has formed the basis for the work within ISO. A Nordic interlaboratory study has been performed as a basis for international standardization as ISO 9705 /11/.

The room corner test has been the main full-scale fire scenario used in the Scandinavian research /11, 24, 27/. It provides about the same basic data as the cone calorimeter e.g. rate of heat release and rate of smoke release, only mass loss can not be obtained. The time to flashover is often given as a simple and overall test result. It means visible flames out of the doorway, which is equivalent to about 1000 kW in rate of heat release. Data for all 28 products are given in Table 1.

Wood products generally have 2 to 3 minutes to flashover when the linings are applied to both walls and ceiling with an ignition source of 100 kW for the first 10 minutes and then raised to 300 kW for another 10 minutes if flashover is not reached. These have been the conditions used in almost all tests in the Scandinavian program.

A few tests have been performed with linings on walls or ceiling only /24/, see Table 2. Especially the ceiling case increases the time to flashover substantially. More experience from applications on walls only has been gained in the US, but they have also used other ignition sources, e.g. 40 and 160 kW, so the results are hard to compare. However, applications of the same material to either walls and ceiling seem more realistic and similar to practical use.

Table 2. Time to flashover in room corner test for different applications of surface linings /24/.

Particle board on	Time to flashover min:s
both walls and ceiling	2:30
walls only	4:08
ceiling only	13:55

Some tests have also been performed in a larger room, about 9 x 7 x 5 m, with linings on both walls and ceiling. The ignition source was in this case increased to 300 kW for the first 10 minutes followed by 900 kW for the next 10 minutes /9/. Flashover was reached only with two linings and was close with another one, but occured much later than in the smaller room corner test, see Table 3. This shows clearly that surface linings are less important for the fire growth in larger rooms.

Table 3. Time to flashover in large-scale room and in room corner test /9/.

	Time to flashover, min:s	
	Large-scale room ~ 9 x 7 x 5 m	Room corner 3.6 x 2.4 x 2.4 m
Combustible faced mineral wool	21:40	1:20
Birch plywood	19:30	2:30
FR particle board (B1)	> 32:00	10:30
PVC wallcarpet on gypsum board	> 27:00	10:55
Textile wall-covering on gypsum board	> 25:00 (close to f.o. at 11:05)	11:20

MODELS AND CORRELATIONS BETWEEN SMALL-SCALE AND FULL-SCALE DATA

The first fire research program resulted in three models which were applied to the 13 products used then /10, 18, 28/. Later these models have been further developed and applied to more materials /7, 21, 30 /.

One model /6, 7/ is quite general and makes use of data from both the cone calorimeter and other small-scale tests as surface spread of flame. It can be simplified to use only cone calorimeter data. The rate of heat release in the room corner test is calculated in both cases. Some examples for wood products are given in Figure 2. This model can be used for different fire scenarios. It has also been applied to the 1/3 scale model room.

Another model /28, 30/ can also calculate the rate of heat release, but it is restricted to the room corner test, since it is based on observations during this test. Only data from the cone calorimeter are needed. Some examples are given in Figure 3.

The third model /18, 21/ is simpler and correlates time to flashover in the room corner test with basic data from the cone calorimeter, see Figure 4. The density of the material is included as a simple measure of the thermal inertia. Similar regressions are obtained for the set of 13 products and for all 28 products, which is a strong indication of its predictive capacity.

All of these models are useful as a basis for classification of surface products. They differ in complexity and field of application.

Recently, an advanced field model have been applied to model the spread of flame in the room corner test /14/.

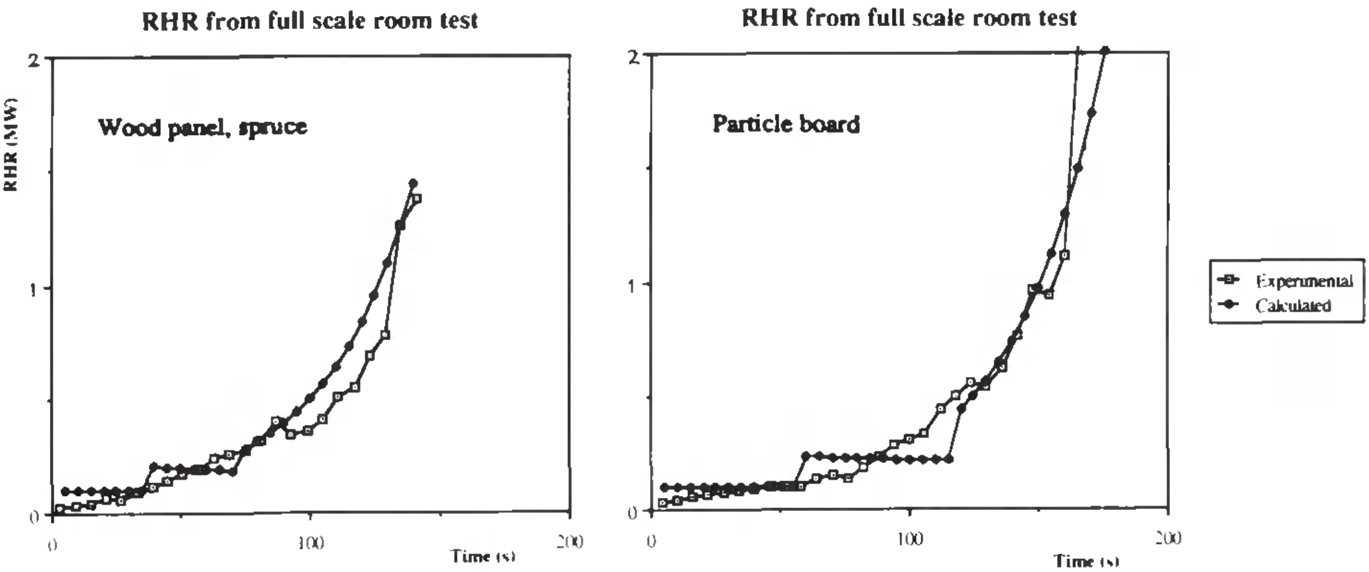

Figure 2. Experimental and calculated rate of heat release, RHR, according to the model from Lund University /7 /.

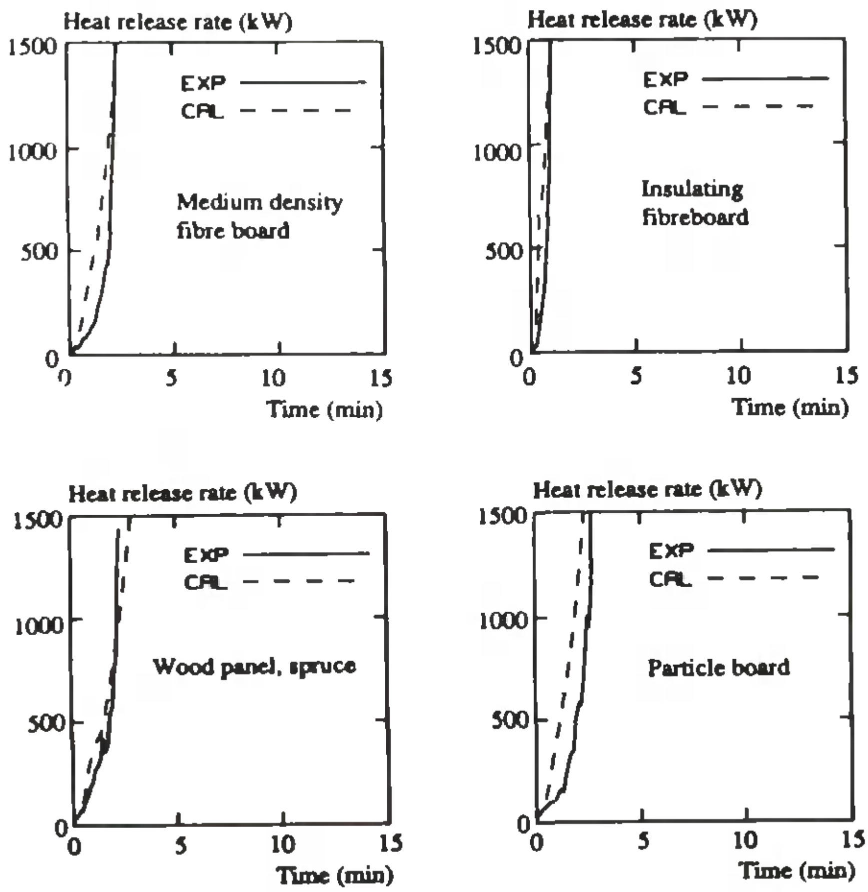

Figure 3. Experimental and calculated rate of heat release in the room corner test according to the model from SP /30 /.

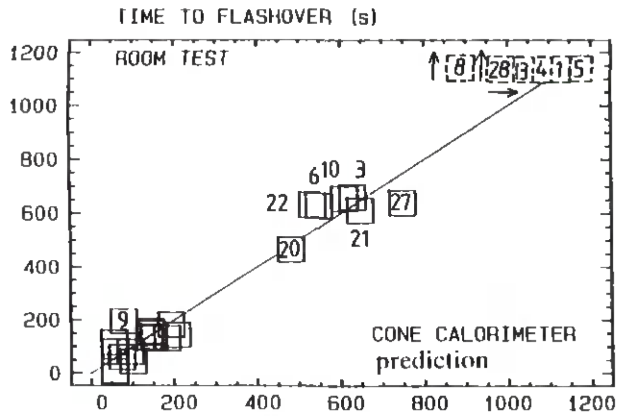

Figure 4. *Experimental and predicted time to flashover in the room corner test according to the correlation model from Trätek /21 /. Correlation coefficient 0.974.*

Smoke models are not yet available, but some correlations have been obtained between smoke data from the cone calorimeter and the room corner test /20/. The correlations are most reliable for products which have more than 10 minutes to flashover, see Figure 5. These products are most important to check for smoke, since some of them produce large amounts of smoke in the room corner test even if they do not reach flashover within 20 minutes. The smoke production may thus be critical for their fire classification.

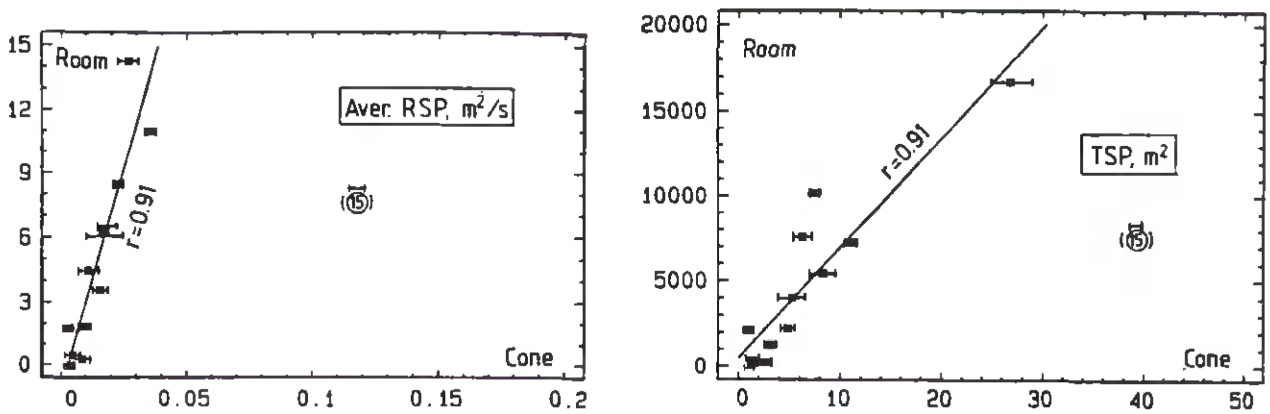

Figure 5. *Smoke correlations between data in the cone calorimeter and the room corner test /20 /. The best correlations are obtained for products with more than 10 minutes to flashover. To the left rate of smoke production, RSP, and to the right total smoke production, TSP, which both have a correlation coefficient, r, of 0.91.*

CLASSIFICATION OF SURFACE PRODUCTS

The classification of the reaction-to-fire of surface products differ from country to country. The main reason is old fashioned test methods which can not handle new materials in a realistic way corresponding to real full-scale fire behaviour.

A new proposal for classification based on the room corner test has been presented in the Eurefic program /25/, see Table 4. Products are divided into five classes, A to E, or even six if unclassified products are included. This seems to be too many classes especially when comparing with the present national classifications in Europe. Some of the classes, e.g. class C, gets very few products. For wood the Eurefic proposal might seem unfavorable, since wood gets into the lowest class E, with only unclassified products as considered to be more unsafe.

Table 4. Eurefic proposal for classification of surface products tested in the room/corner test /25/.

Class	Minimum time	Heat release rate, max		Smoke production, max	
		peak	average	peak	average
	(min)	(kW)	(kW)	(m^2/s)	(m^2/s)
A	20	300	50	10	3
B	20	700	100	70	5
C	12	700	100	70	5
D	10	900	100	70	5
E	2	900	-	70	-

An alternative classification would be to make one class of A and B and another of C and D, getting a system of totally four classes:

- > 20 minutes to flashover
- 10–20 " "
- 2–10 " "
- < 2 " "

This has been applied and compared with some national classifications /1,3,4,15,17/ in Figure 6, giving about the same number of classes as today. However, there is a tendency that some products get a "better" classification in the national systems and seem to be more safe than they are in room corner test. The opposite is true for some products showing that all relevant parameters are not taken into account in the national tests.

Time to flashover as predicted from cone calorimeter data /21/ is also included in Figure 6. In this case there is a better agreement. A few products have shorter predicted time than measured, which is on the safe side, as a better classification might be reached by a full-scale test. No products are on the unsafe side, as for the national classifications.

An approach with indices for classification based on cone calorimeter data has also been proposed /8/, but not yet further evaluated.

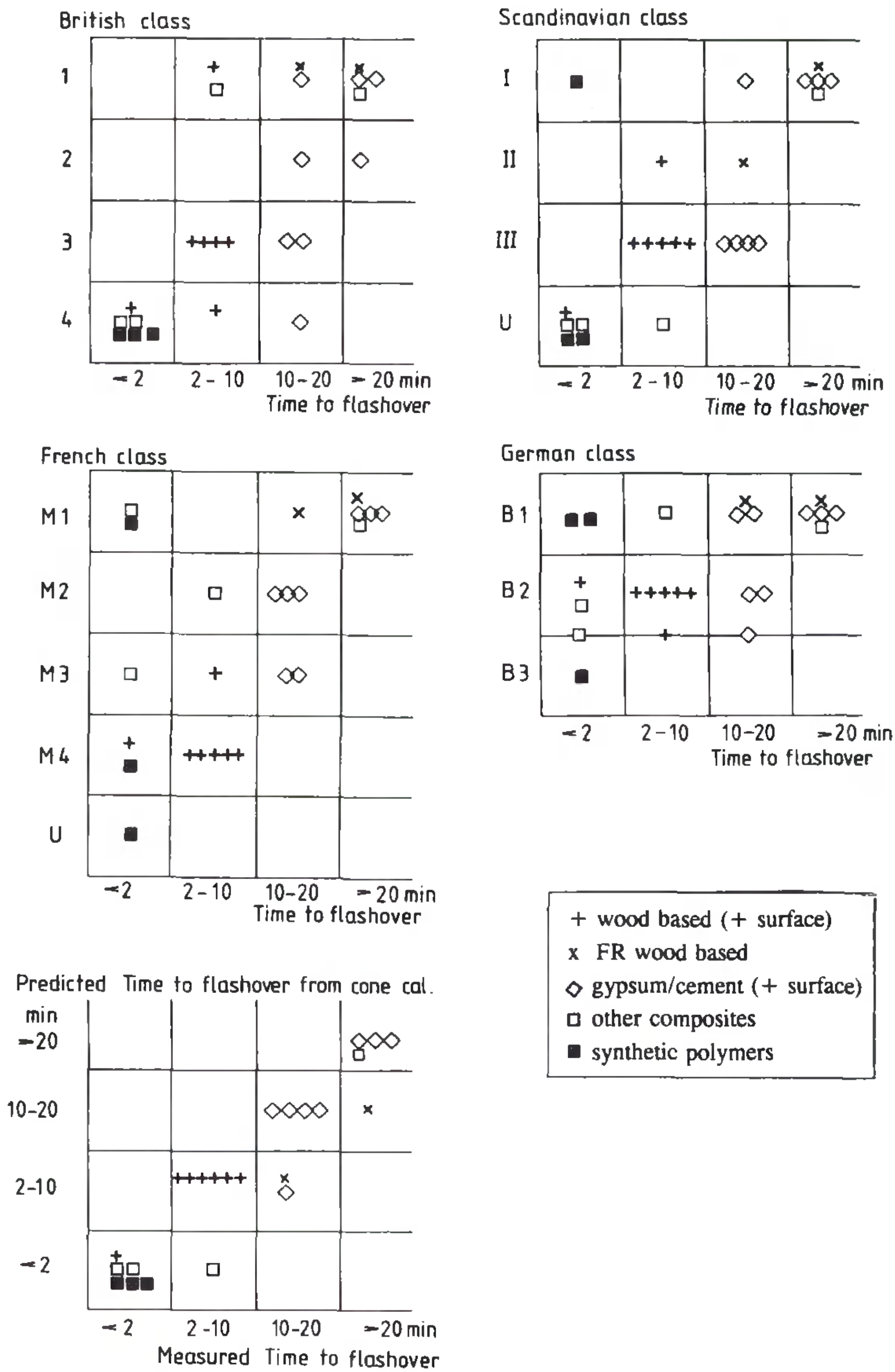

Figure 6. Alternative classification of surface products according to time to flashover in the room corner test compared to the present national classifications in some European countries. Below, predicted time to flashover from cone calorimeter data /21/ is used for classification giving a better agreement with the full-scale behaviour.

EFFECTS OF FIRE RETARDANTS

Only two fire retardant wood products were included in the major research program. They both had a quite good fire performance, see Figure 6.

Some more wood products were evaluated earlier /15/ and have recently been tested also in the cone calorimeter. Predicted times to flashover have been calculated /21/ and are compared with some national classifications in Figure 7. In many cases the fire retardant wood get a longer time to flashover than untreated wood. In other cases they get about the same, e.g. 2–10 minutes to flashover, while national classifications are better. This is understandable, since retardant treatments often are developed to pass a test. In these cases, new formulations might be needed to pass a more realistic test. But there is no doubt that fire retardant wood products might get a good classification according to a new system based on the cone calorimeter and the room fire test.

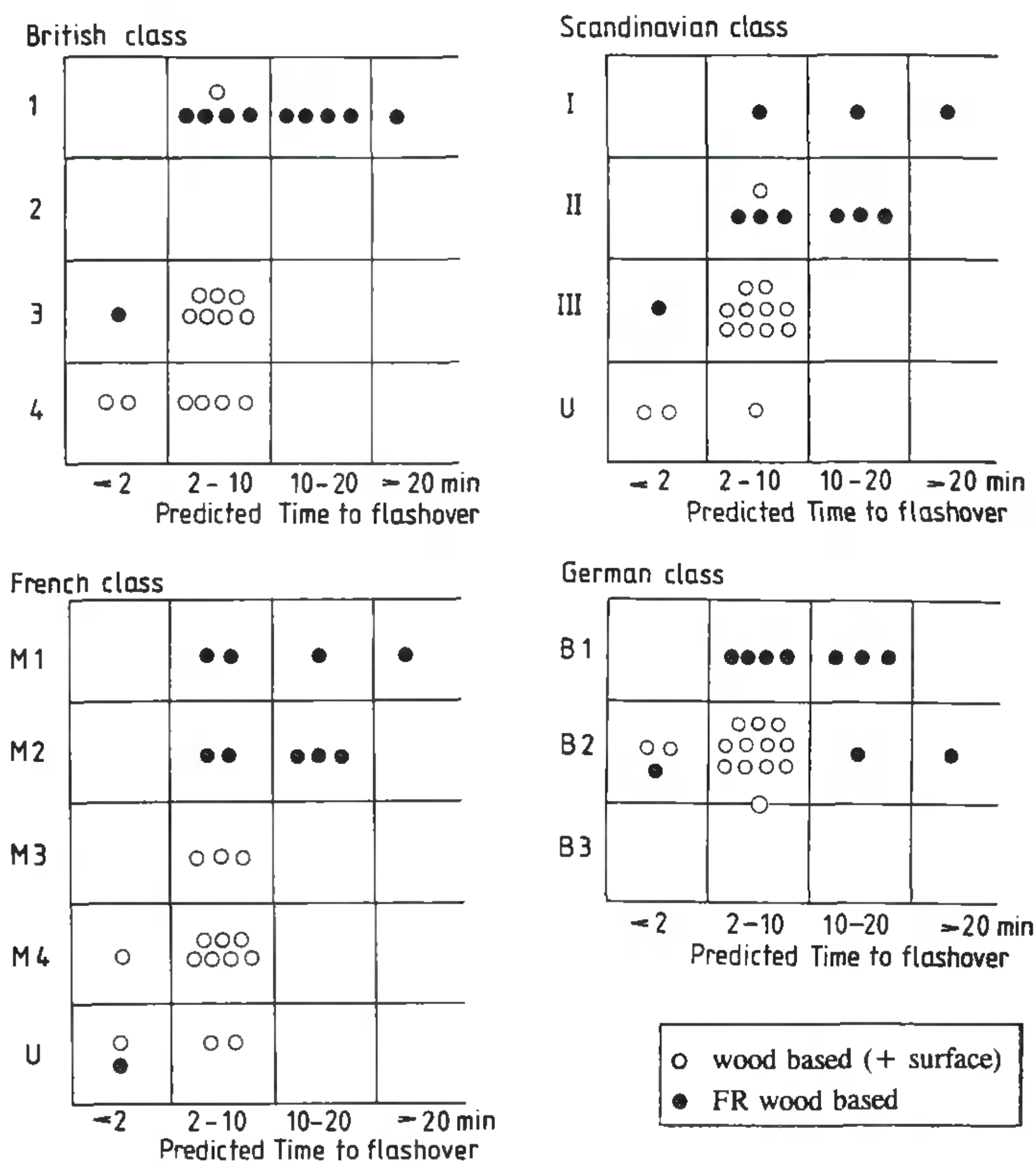

Figure 7. Classification of wood products according to national systems /1,15,17/ and to predicted time to flashover according to the Trätek model /21/.

CONCLUSIONS - NEED FOR FURTHER RESEARCH

The Scandinavian research programs on reaction-to-fire have demonstrated the benefits with applying new technology in fire testing and modelling: A safer system based on full-scale fire behaviour and deletion of trade obstacles. The system is basicly ready for European standardization and implementation, but experience is still lacking in several countries.

Further research might be needed in some areas. In full scale, other fire scenarios, ignition sources and applications of linings should be studied. Combinations with building content is also lacking. In small scale, further refinement of experimental techniques and application of test data is needed. In modelling, other fire scenarios should be studied. Models for smoke are of special interest. When results of such further research are available, the standards can be revised.

For wood, it is especially important to reach a fair classification in relation to other surface products, not being the worst since there are many products on the market which are much more unsafe than wood. A classification system with about four classes for surface linings should be developed as suggested above.

Smoke production should be included in the classification system since many products produce a lot of smoke even if they do not reach flashover.

The wood industry and its organizations in Europe should put emphasis on fire issues. Other industrial branches, e.g. the plastic industries, have been much more active.

Regulators should also be more aware of the possibilities with using new technology to achieve fire safety and facilitate free trade in Europe.

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Trätek

INSTITUTET FÖR TRÄTEKNISK FORSKNING

Box 5609, 114 86 STOCKHOLM
Besöksadress: Drottning Kristinas väg 67
Telefon: 08-14 53 00
Telefax: 08-11 61 88

Åsenvägen 9, 553 31 JÖNKÖPING
Telefon: 036-30 65 50
Telefax: 036-30 65 60

Skeria 2, 931 87 SKELLEFTEÅ
Besöksadress: Laboratorgränd
Telefon: 0910-652 00
Telefax: 0910-652 65