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Building Fire Safety and Hazard Assessment Methods for Combustible Surface Finishes

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BUILDING FIRE SAFETY AND HAZARD ASSESSMENT METHODS FOR COMBUSTIBLE SURFACE FINISHES

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ABSTRACT

In most countries, useful engineering tools are not available to assess the real impact of combustible room lining materials on the fire safety of buildings. Instead small-scale fire tests have traditionally been used to “rank” materials and to achieve the necessary “index” or “class” set down in building regulations.

Research in fire science has led to many improved engineering tools and methods for predicting fire and smoke spread and the structural response of buildings to fire, but prediction and evaluation of flame spread over materials and assessment of its impact on the fire safety of the building has generally lagged behind.

This paper discusses developments in the area of evaluating the contribution of combustible surface finishes to fire hazard and latest trends in international building regulations for controlling the fire properties of combustible room linings. Research and regulatory trends in Europe and in Australia, in particular, are discussed. Performance based design methods which complement these new regulatory approaches are also discussed and a calculation tool developed by the Building Research Association of New Zealand (BRANZ) is described and compared with a series of experimental results. The tool is the computer program (BRANZFIRE) for predicting flame spread, heat release and smoke spread resulting from fire in buildings.

KEYWORDS:

Fire Safety, Materials, Performance, Software, Flame Spread

INTRODUCTION

Fire development in rooms is influenced by a wide range of factors, such as the nature of the room contents and type of wall, ceiling and flooring materials; the size and geometry of the room; available ventilation; the presence of automatic suppression systems; and the characteristics of ignition sources.

The contribution that room-lining materials make to the hazard in a room must be considered along with the likely contribution from room contents. In some instances the contents may dominate the fire hazard. However, the flammability of room contents is often unrestricted with building codes tending to focus only on the design and construction of the building. Consideration of the flammability of room linings is more important for spaces where large numbers of people are present, where occupants have poor mobility or are restrained, and within major exitways and escape routes. Building occupants require enough time for escape prior to the room linings making a significant contribution to the fire.

The traditional “prescriptive” approach to regulating the control of room lining materials has been to test samples of material in small-scale fire tests such as the AS/NZS 1530 Part 3 test (SA, 1999) used in Australia and New Zealand. This test places a 450 x 600 mm vertical sample of material opposite a gas-fired radiant panel. The sample is moved toward the radiant panel during the test and measurements are made of:

- ignition time
- radiation (from the face of the sample)
- smoke optical density.

These measurements are used to produce four indices: ignitability index, spread of flame index, smoke developed index and heat-evolved index. Of these, only two are used in regulations controlling room lining fire performance. They are: the spread of flame index and the smoke developed index.

While the test has served a useful role in ranking the behaviour of different materials for building control purposes, it is also known to have limitations and its ability to relate to expected performance in full-sized rooms has been questioned. Gardner and Thompson (1988) investigated whether a correlation existed between the flashover time in a room fire test and the flame spread index from AS 1530.3, and found none. The Fire Code Reform Centre (FCRC, 1998) also identified further shortcomings of the test method including: some materials that are known to ignite and burn when exposed to a gas burner in a room corner do not ignite in the AS/NZS 1530.3 test; the levels of impressed radiation in the test are not the same for all materials since the radiation level is not increased following ignition of a sample; and the method for measuring smoke was stated to be arbitrary and technically flawed.

Given today's emphasis toward performance-based design there is a greater expectation that small-scale fire test results used in building regulations should have a strong relationship with expected fire behaviour in full-sized rooms, and this has been the main international research focus over the last decade.

RESEARCH AND REGULATORY TRENDS

The EUREFIC Project

The EUREFIC project (EUropean REaction to FIre Classification) started in 1989 and primarily involved the Nordic countries Denmark, Finland, Norway and Sweden (ICL, 1991). It was intended to develop evaluation methods based on the cone calorimeter and the room/corner test for wall and ceiling linings and to develop appropriate classification criteria based on these methods. The ISO 9705 room corner test (see Figure 1) comprises a room 3.6 m x 2.4 m x 2.4 m with a 2 m x 0.8 m door opening (ISO, 1990). The test material is fixed to the interior walls and ceiling and ignited with a gas burner in a corner of the room. Smoke and gases leaving the room are collected in a hood and analysed using oxygen calorimetry techniques, allowing rate of heat release and other measurements to be made. The output of the gas burner is set to 100 kW for the first 10 minutes and if no ignition has occurred during this period the burner output is increased to 300 kW.

They proposed that materials be classified into five groups based on the measured time to flashover in the ISO 9705 room/corner test. In simple terms, the groups are defined as:

Class A: materials that result in a peak rate of heat release of not more than 600 kW after 20 minutes
Class B: materials that result in a peak rate of heat release of not more than 1000 kW after 20 minutes
Class C: materials that result in flashover after 12 minutes but before 20 minutes
Class D: materials that result in flashover after 10 minutes but before 12 minutes
Class E: materials that result in flashover after 2 minutes but before 10 minutes

Materials that resulted in flashover before 2 minutes were "unclassified". There were also limits placed on average rate of heat release and smoke production. These are not discussed further here.

Regulatory authorities and the European Community did not adopt the recommendations of the EUREFIC project.

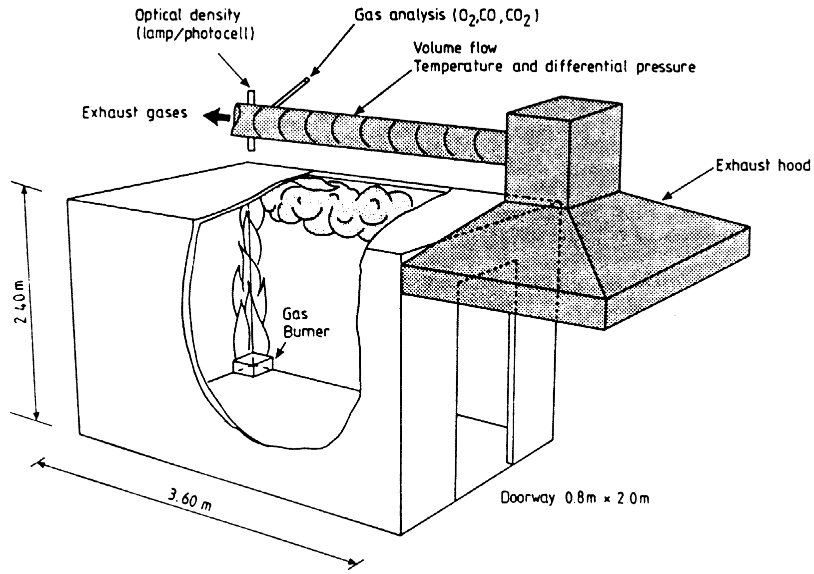


Figure 1: The Standard Room Fire Test – ISO 9705

The Euroclasses

In 1994, member countries in the European Community did however agree to use the same fire test methods and classification system for surface lining materials. The classification system is primarily based on a Fire Growth Rate (FIGRA) index determined from the Single Burning Item (SBI) test. The approach adopted was one of political compromise and to that end was considered a success. However, in terms of making a contribution to performance-based engineered design the solution has been strongly criticised (Babrauskas, 1997; Karlsson et al, 2000). On the other hand the SBI test has been reported as being the most extensively and thoroughly evaluated fire test method ever developed (Deakin, 2000) and a link with the larger scale reference scenario for rate of heat release behaviour has been demonstrated (Tsantaridis and Östman, 1998) leading the way for the use of the test as part of the European solution.

A single reference scenario has been used as the basis for the Euroclass classification system. This is a fire starting in a small room and growing to reach flashover. The large-scale reference test to represent this scenario is ISO 9705 (the room corner test). The smaller SBI test is also intended to simulate fire growth in the corner of a room and has been correlated with the reference test. It comprises a trolley-mounted frame carrying two adjoined walls 594 mm long x 1000 mm wide x 1500 mm high and is located in a ventilated enclosure. A gas burner in the corner exposes the wall to a heat flux of 40 kW/m^2. The FIGRA Index for the SBI test is the maximum value of a 30 second running average rate of heat release divided by the time at which this occurred.

The Euroclasses consist of seven categories; A1 (best), A2, B, C, D, E, F (worse). Four fire test methods are used to determine the appropriate class for a given material. These tests are: the single burning item test, non-combustibility test, determination of gross calorific value test, and small flame ignitability test (Anon, 1999).

Fire Code Reform Centre

More recently, the Fire Code Reform Centre in Project 2A (FCRC, 1998) concluded that time to flashover in the ISO room was the appropriate parameter to use for regulatory purposes. Time to flashover was again defined as the time taken for the heat release rate to reach 1 MW from the ISO room. The research proposed that materials be grouped into one of four categories based on time to flashover (when tested in ISO 9705 standard room test) as follows (see also Figure 2):

Group A	materials that result in flashover in less than 120 seconds
Group B	materials that result in flashover in more than 120 seconds but less than 600 seconds
Group C	materials that result in flashover in more than 600 seconds
Group D	materials that do not result in flashover

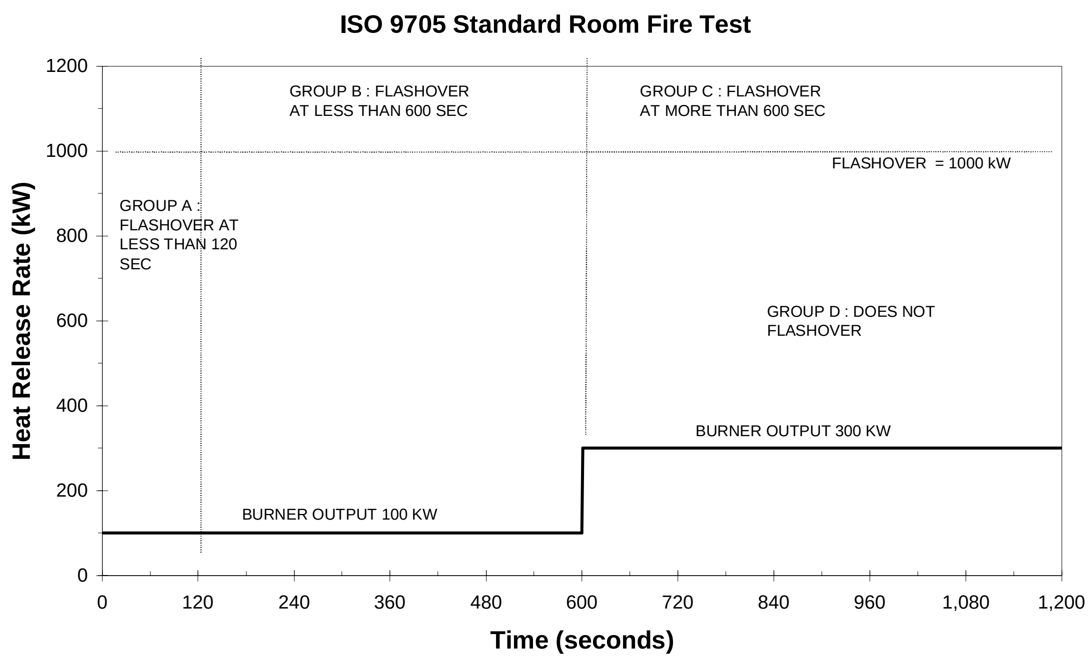


Figure 2: Proposed FCRC Project Classification System

They also concluded that it was acceptable for small-scale test results to be used in conjunction with a mathematical model in order to predict the time to flashover in the ISO room fire test, as an alternative to carrying out the large-scale test.

They identified that the cone calorimeter test was able to provide appropriate small-scale fire test data for predicting time to flashover in the room corner test. They reviewed the SP model (Wickström and Göransson, 1992), the Classification Index proposed by Kokkala et al (1993) and the Östman relationship (Östman and Tsantaridis, 1994) and concluded that the Classification Index of Kokkala was the most suitable method for use with routine testing of many wall and ceiling linings.

Such an approach is consistent with an engineering basis for regulation of surface lining materials. However the approach is also readily extended into performance-based design, whereby use of a more generic calculation tool may allow time to flashover predictions for room configurations and fire scenarios which vary from the ISO 9705 room corner reference case. Not only would it be possible to account for the actual room size, ventilation conditions, and ignition source strength but also the common case of rooms with different materials used on walls and for ceilings could also be accommodated.

An example of such a proposed generic calculation tool is the BRANZFIRE fire model (Wade 2000; 1996; Wade and Barnett, 1997; Wade et al 1997).

THE BRANZFIRE MODEL

BRANZFIRE is a zone model including flame spread options on walls and ceilings and is used to calculate the time dependent distribution of smoke, fire gases and heat throughout a collection of connected compartments during a fire. In BRANZFIRE, each compartment is divided into two layers. The conservation equations used in BRANZFIRE take the mathematical form of an initial value problem for a system of ordinary differential equations (ODE). These equations are derived using the conservation of mass, the conservation of energy, the ideal gas law and related equations for density and enthalpy. These equations predict time varying quantities such as pressure, layer heights and temperatures given the accumulation of mass and enthalpy in each layer. The BRANZFIRE model solves the set of ODE's to determine the environment in each compartment layer. The model incorporates the production of species, including carbon monoxide, which are important to the safety of individuals subjected to a fire environment.

BRANZFIRE models multiple compartments, with horizontal or vertical vents connecting compartments to each other or to the outside. Mechanical ventilation, optional ignition and flame spread on walls and ceilings, sprinklers and detector activation, visibility and calculation of fractional effective dose based on oxygen, carbon dioxide and carbon monoxide concentrations are also included.

The flame-spread algorithms are based on thermal flame spread theory. Both upward (wind-aided) and lateral flame spread is modeled. Ignition is predicted making use of the Flux Time Product method (Silcock and Shields, 1995) based on analysis of cone calorimeter time to ignition data. Heat release contribution by linings is determined based on the calculated pyrolysis area and time dependent heat release data from cone calorimeter tests.

The peak heat flux from the burner to the wall/corner surface, Q_p, is approximated using:

$$Q_p = 130\left(1 - e^{-0.09 Q_b^{1/3}}\right) \quad [\text{kW/m}^2]$$

Q_b is the nominal heat output from the burner (kW). The expression equates to 44.4 kW/m^2 for a 100 kW gas burner output and 58.8 kW/m^2 for a 300 kW gas burner output. The heat flux over the lower 40% of the flame height is assumed to be uniform and equal to the peak flux above following the findings of Back et al (1994). The side dimension of the burner and 40% of the flame height defines the region or area first ignited by the burner flame. The flame height is based on a correlation for a corner configuration using Kokkala's revised Heskestad correlation (Kokkala, 1993a).

$$L_f = \text{Burner Dimension} * [-2.04 + 6.62 * (Q_b / (1110 * \text{Burner Dimension}^{(5/2)}))^{(2/5)}]$$

Other details of the model theory and assumptions are given by Wade (2000).

COMPARING BRANZFIRE PREDICTIONS WITH LARGE-SCALE TESTS

Three building materials (as shown in Table 1) were used to line a room conforming to ISO 9705 (Dowling et al, 1999). A series of full-scale fire tests were carried out following the ISO 9705 procedure. These experiments included paper-faced gypsum plasterboard fixed to the walls and ceiling of the room, a plywood material fixed to the walls and ceiling, and then separately to the walls and ceiling respectively, and then the same for a fire retardant-treated plywood material. Table 2 records the measured time to reach 1000 kW (flashover) in each experiment along with the predicted time using BRANZFIRE (version 2001.1).

Table 1: Materials Used in CSIRO Room Fire Experiments

Material	Description	Thickness (mm)	Density (kg/m^3)
Plasterboard	Paper-faced, glass-reinforced gypsum plaster	16	810
Plywood	Three-ply lauan	4	580
Plywood, FR	Three-ply hoop pine, “FIREX” impregnated	4	580

Dowling et al (1999) compared several correlations as well as the BRANZFIRE model with the experimental data and noted that the BRANZFIRE model was not able to adequately predict the rate of heat release behaviour of the fire retardant plywood material. Changes were subsequently made to the model including changing the method of correlating the cone calorimeter ignition data to the Flux Time Product (FTP) method of Silcock and Shields (1995), changes to the incident heat flux and burner flame height as described previously, and also by making use of cone calorimeter data obtained for the material at a range of external heat fluxes rather than from only a single heat flux. These improvements to the model resulted in improved agreement with the experimental data for the fire retardant ply as shown in this paper.

Table 2: Time to Flashover and Classification for Materials Tested in the ISO Room Fire Test: Comparison of Experimental Times and BRANZFIRE Predicted Times**

Material	*Experimental time (s)*	*BRANZFIRE time (s)*
Walls only		
Plywood	163* (Group B)	119 (Group A)
Plywood, FR	260 (Group B)	238 (Group B)
Ceiling only		
Plywood	400 (Group B)	255 (Group B)
Plywood, FR	535 (Group B)	465 (Group B)
Walls and Ceiling		
Plywood	125 (Group B)	95 (Group A)
Plywood, FR	190 (Group B)	102 (Group A)
Plasterboard	N (Group D)	N (Group D)

*average of two tests

** according to FCRC (1998) recommendations

The BRANZFIRE model results in the materials being correctly classified following the FCRC recommendations (FCRC, 1998) in four of the seven configurations as shown in Table 2. In the remaining three cases, the model predicted a more rapid fire growth rate than occurred in the experiments and placed the materials in Group A instead of Group B. In one of those three cases (plywood on walls only), the classification was borderline falling just one second below the transition from Group A to Group B. Although the model results are mixed in terms of correctly classifying the products, the conservative nature of the prediction ensures the usefulness of the approach for performance based engineering applications or as an initial screening tool.

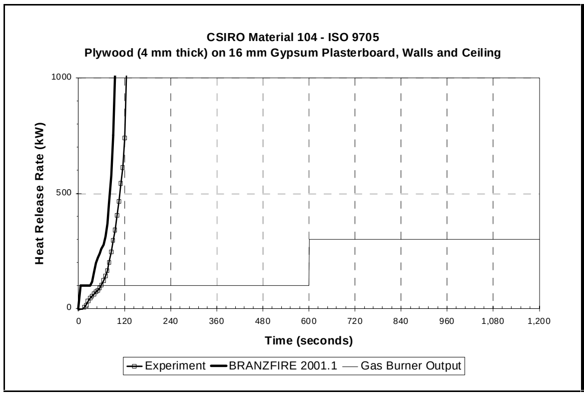
Figure 3 shows the measured and predicted rate of heat release histories for each experiment. Graphs E and F show a spike in the heat release rate curve coinciding with a transition to ventilation limited burning. These curves for the predicted heat release rate include both energy release inside the room and that from any burning that is taking place immediately outside the room where unburned fuel carried away in the vent flow mixes with oxygen and combusts outside the room.

There is also inherent uncertainty both in the repeatability of the full-scale experiments and in the small-scale experimental data used as input to the model. Kokkala (1993) investigated the reproducibility of the ISO 9705 test examining the results of an ISO interlaboratory calibration where three or four tests were carried out on each of four different products. Each laboratory conducted only one test on each product. For a birch plywood product the mean of the time to reach 1 MW was 137 seconds but the 95% confidence interval was determined to be 100 – 174 seconds (ie 137 ± 37 seconds). Dowling et al (1999) also carried out a repeat test for plywood fixed to the walls only - the mean of the time to reach 1 MW was 163 seconds and the 95% confidence interval for the mean was determined to be 145 – 181 seconds (ie 163 ± 18 seconds) based on two tests. Janssens (2000) recently presented estimates for the uncertainty in the peak heat release rate measured in room fire tests indicating a 95% confidence interval of ± 65% for repeatability and ± 79% for reproducibility. Overall experimental uncertainty is high and this should be borne in mind when comparing model predictions with experimental data.

Although the classification method using the standard ISO 9705 test would normally be carried out with the same material fixed to the walls and ceiling, there seems to be no reason why combinations of material could not be specified ie a different material on the wall and ceiling, with the resulting performance following the room test procedure to determine the classification of the particular system. Full-scale room testing would be required for this (or an approved modelling tool). Correlations using cone calorimeter data to predict full-scale results would not be applicable if they were only derived from data where both walls and ceilings are lined with the same material.

To provide comparisons with a wider range of materials/products, Figure 4 shows similar information for products from the EUREFIC project (ICL, 1991). The EUREFIC ordinary plywood product is not shown as it is quite similar to that shown in Figure 3(A). Only those materials for which there was sufficient quality of small-scale cone calorimeter data available are shown. The BRANZFIRE model results in the materials being correctly classified following the FCRC recommendations (FCRC, 1998) in four of the nine configurations, but nonetheless a conservative classification in seven out of nine cases. There were two EUREFIC products (C, F) that resulted in flashover after 600 seconds, but where BRANZFIRE predicted no flashover in 20 minutes. The first of these was a textile wall covering on plasterboard, where the predicted peak heat release rate was about 900 kW - this was close to the 1000 kW flashover criterion. The second product was a fire retardant treated particleboard, which was predicted to have a maximum heat release rate of just under 600 kW.

The comparative data shown in this paper focuses on the rate of heat release, as this is the most important parameter influencing the fire hazard in a building. The BRANZFIRE model uses this rate of heat release prediction to subsequently carry out mass and energy balance calculations to make further predictions about the gas temperatures, combustion product species concentrations and other parameters used to evaluate tenability of smoke conditions within a building.



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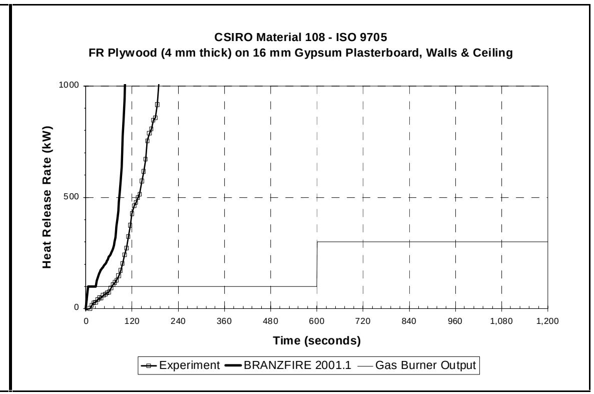

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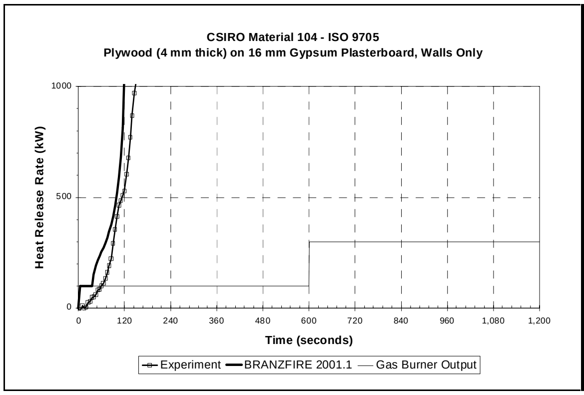

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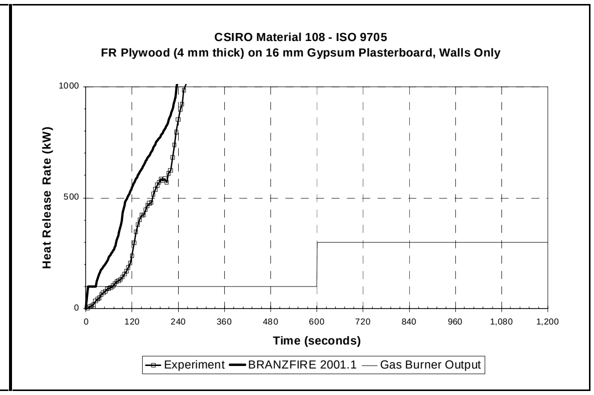

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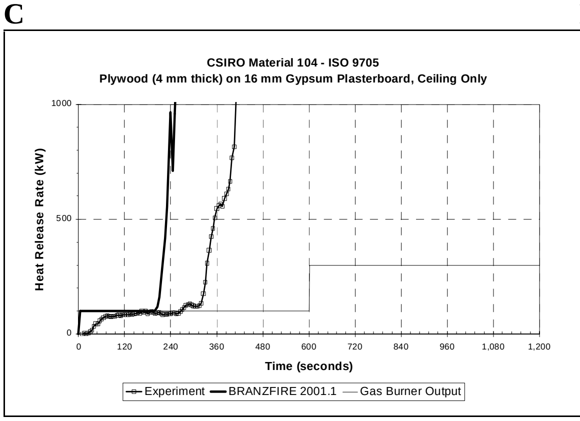

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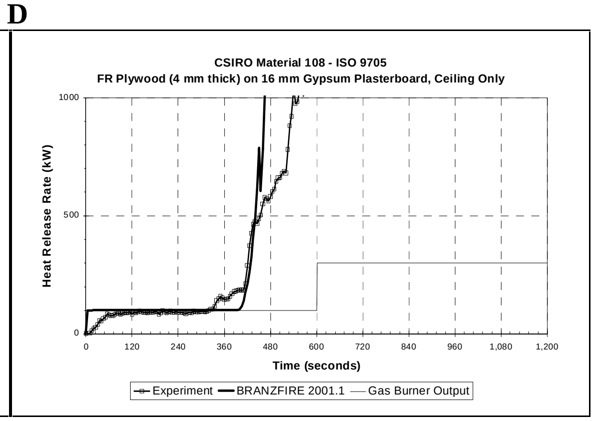

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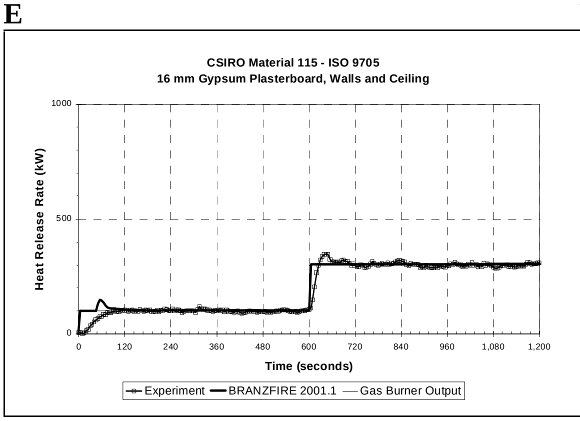

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Figure 3: Comparison of Predicted and Measured Heat Release Rates from CSIRO Experiments

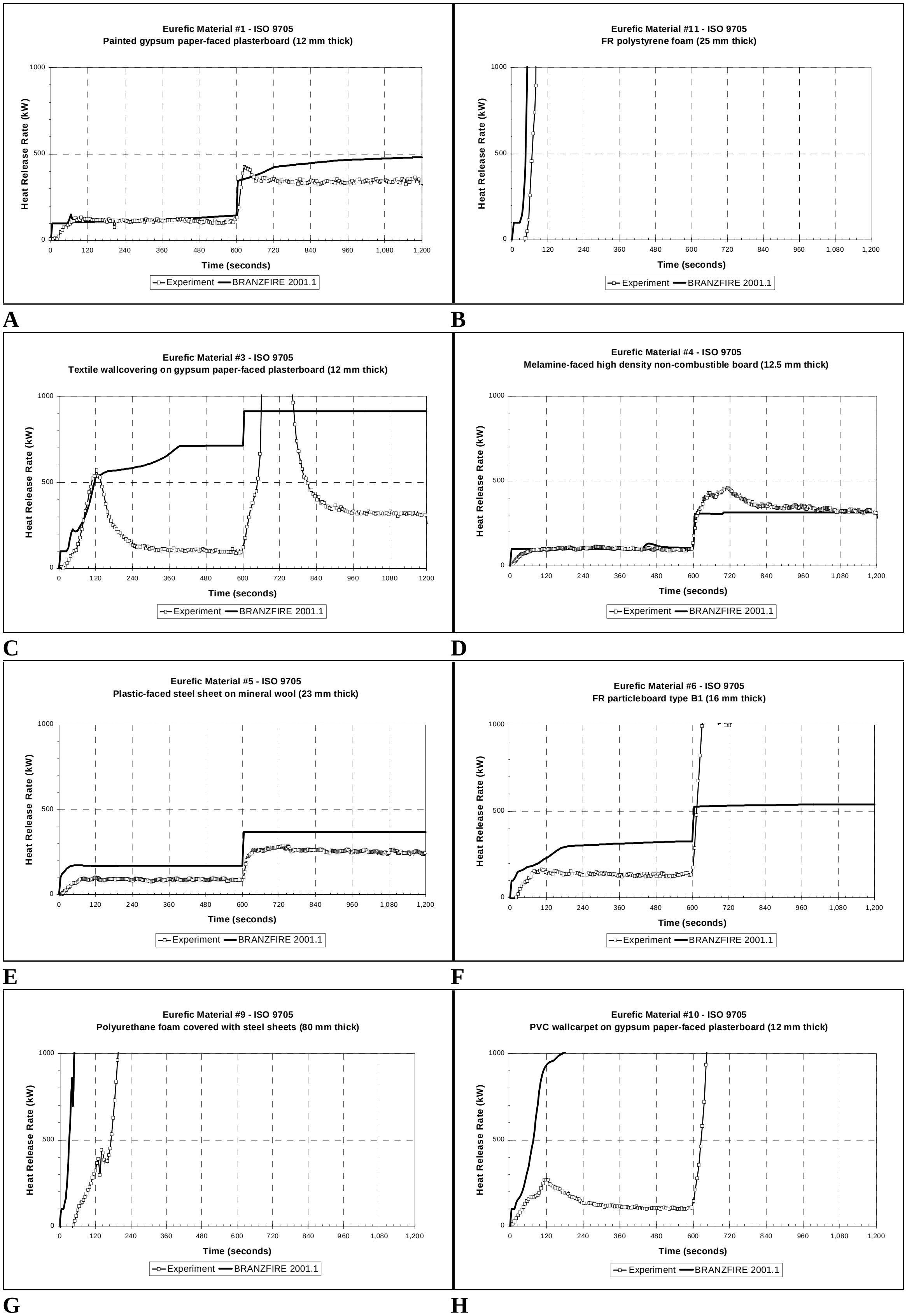

Figure 4: Comparison of Predicted and Measured Heat Release Rates from EUREFIC Experiments

The BRANZFIRE modelling results are sensitive to the heat flux assumptions from the burner flame to the room surfaces, and further work is warranted in this area for heat fluxes applicable for a wider range of ignition types and sources. Also the quantity and quality of the small-scale cone calorimeter data has an important effect on the ignition correlations and subsequent prediction of ignition times and flame spread rates. It is desirable for cone calorimeter data covering a wide range of heat fluxes to be used. Data for three different external heat fluxes levels is the minimum requirement however more is desirable to increase the accuracy and confidence level of the ignition correlations.

CONCLUSION

Current reaction to fire test methods such as AS/NZS 1530 Part 3 (SA, 1999) do not adequately classify materials in accordance with their expected behaviour in the full-scale room test and do not provide adequate engineering data for performance-based design.

New classification systems based on time to flashover in the standard room test are more appropriate for regulatory purposes. Full-scale testing need not be a requirement if small-scale test data (eg cone calorimeter) when used with an accepted correlation can be shown to correlate with the larger room corner scale. The approach can be extended to support performance-based fire engineering design through the use of more generic and flexible calculation models such as the BRANZFIRE model that permit hazard assessment of not only ISO standard room sizes but also other room sizes.

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REFERENCES

Anon, 1999. Class Distinction. Fire Prevention 316, p15-17. January 1999.

Babrauskas, V. 1997. “Redefining the Value of π in the European Union”, Editorial, Fire Safety Journal 29.

Back, G., Beyler, C., DiNenno, P and Tatem, P. 1994. Wall Incident Heat Flux Distributions from an Adjacent Fire. Fire Safety Science – Proceedings of the Fourth International Symposium. Ottawa.

Deakin, G. 2000. http://www.wfrc.co.uk/useful_publications/harmonised_fire_safety.htm

Dowling, V., McArthur, N.A., Webb, A.K., Leonard, J.E., and Blackmore, J. 1999. Large Scale Fire Tests on Three Building Materials. Proceedings 3rd International Conference on Fire Research and Engineering, Chicago.

Fire Code Reform Centre (FCRC). 1998. Fire Performance of Wall and Ceiling Lining Materials. Final Report – With Supplement. Project Report FCRC–PR–98-02.

Gardner, W.D. and Thompson, C.R. 1988. Flame Spread of Forest Products - comparison and validation of prescribed Australian and North American flame spread test methods. Fire & Materials, 12, p71-85.

Interscience Communications Ltd (ICL). 1991. EUREFIC European Reaction to Fire Classification. Proceedings of the International EUREFIC Seminar, Copenhagen Denmark, September 1991.

International Standards Organisation (ISO). 1990. ISO 9705 Room fire test in full scale for surface products.

Janssens, M. 2000. Heat Release Rate (HRR). Ohlemiller, T. J., Johnsson, E. L., and Gann, R. G., eds., Measurement Needs for Fire Safety: Proc. of an Intl. Workshop (NISTIR 6527), National Institute of Standards and Technology, Gaithersburg MD.

Karlsson, B., North, G., and Gojkovic, D. 2000. "Towards Using Results from Performance Based Test Methods for Material Flammability in Fire Safety Engineering Design". *In* "Proceedings, 3rd International Conference on Performance-Based Codes and Fire Safety Design Methods". Lund, Sweden.

Kokkala, M.A., Thomas, P. H., and Karlsson, B. 1993. Rate of Heat Release and Ignitability Indices for Surface Linings. Fire & Materials 17. p209-216.

Kokkala, M.A. 1993a. Characteristics of a flame in an open corner of walls. Proceedings Interflam '93. Oxford.

Kokkala, M.A. 1993b. Variations in the Room/Corner Test System. Fire & Materials Vol 17 pp217-224.

Östman, B.A. and Tsantaridis, L.D. 1994. Correlation between cone calorimeter data anf time to flashover in the room fire test. Fire & Materials Vol 18. pp205-209.

Silcock, G.W.H and Shields, T.J. 1995. A Protocol for Analysis of Time-To-Ignition Data From Bench Scale Tests. Fire Safety Journal 24, p75-95.

Standards Australia. 1999. AS/NZS 1530. Methods for fire tests on building materials, components, and structures: Part 3 - simultaneous determination of ignitability, flame propagation, heat release and smoke release. Sydney.

Standards Australia. 1998. AS/NZS 3837. Method of testing for heat and visible smoke release rates for materials and products using an oxygen consumption calorimeter. Sydney.

Tsantaridis, L. and Östman, B. 1998. Cone Calorimeter Data and Comparisons for the SBI RR Products. Trätek Report 9812090. Swedish Institute for Wood Technology Research. Sweden.

Wade, C.A. 2000. BRANZFIRE Technical Reference Guide, Study Report No 92. Building Research Association of New Zealand.

Wade, C.A., LeBlanc, D., Ierardi, J., and Barnett, J. 1997. A Room-Corner Fire Growth and Zone Model for Lining Materials. *Proceedings - 2nd International Conference on Fire Research and Engineering*. Maryland.

Wade, C.A and Barnett, J.R. 1997. A Room-Corner Fire Model Including Fire Growth on Linings and Enclosure Smoke-Filling. *Journal of Fire Protection Engineering*. 8 (4) pp 27-36.

Wade, C.A. 1996. A Room Fire Model Incorporating Fire Growth on Combustible Lining Materials. Master of Science Thesis. Worcester Polytechnic Institute, USA. BRANZ Reprint 139. Building Research Association of New Zealand.

Wickström, U., and Göransson, U. 1992. Full-scale/bench-scale correlations of wall and ceiling linings. Fire and Materials Vol 16, pp15-22.