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A New Engineering Tool for Evaluating the Fire Hazard in Rooms

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A NEW ENGINEERING TOOL FOR EVALUATING THE FIRE HAZARD IN ROOMS

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ABSTRACT

This paper discusses research into evaluating the fire hazard in rooms, with particular emphasis on predicting the performance and influence of materials used for lining walls, ceilings and floors. Relevant and useful engineering tools have not been generally available to predict flame spread and fire growth on room lining materials. Instead small-scale fire tests have been used to `rank' materials by their performance in these fire tests to achieve the necessary `indices' set down in building regulations.

Fire engineering design in the next millennium (at least in its earlier years) will most likely involve using small-scale fire test data for lining materials in conjunction with predictive models which will predict the rate of flame spread and fire growth on lining materials when ignited by furniture or other burning objects. The heat and smoke generated by the room contents and linings will spread throughout the room and to other rooms and the predictive models will be used to evaluate the extent of this spread and its hazardous effects on building occupants. These hazardous effects will include excessive temperatures, smoke toxicity and poor visibility.

Research and development of such an engineering tool developed by the Building Research Association of New Zealand will be described. The tool known as `BRANZFIRE' is an engineering computer software program incorporating flame spread, fire growth and smoke spread algorithms. It is intended that on completion, this tool will be used in conjunction with performance-based fire engineering design to provide a realistic prediction of fire hazard in a range of real building design cases, accounting for different room sizes and configurations, ventilation conditions and types of room contents and linings.

With sufficient validation/verification, BRANZFIRE will be used to demonstrate compliance with performance requirements in building regulations as an alternative to carrying out expensive full-scale fire testing (for approval purposes) or relying on small-scale ranking tests of limited applicability.

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. This paper addresses the influence that room lining materials have on the development of hazardous conditions in buildings in the event of fire and better ways of predicting when a hazard may exist.

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.

Examples of major fatal fires where combustible interior finishes were implicated include:

- Stardust Disco, Dublin 1981 - 48 dead,
- Summerland Leisure complex, Isle of Man, 1973 - 50 dead
- Our Lady of Angels School, Chicago, 1958 - 93 dead.

THE TRADITIONAL APPROACH

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 1530 Part 3 test (SA, 1989) 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 AS1530.3, and found none. 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.

Research being done in Australia by the Fire Code Reform Centre (and CSIRO) is addressing these concerns with respect to identifying appropriate methods and building control requirements, but this is not the subject of this paper.

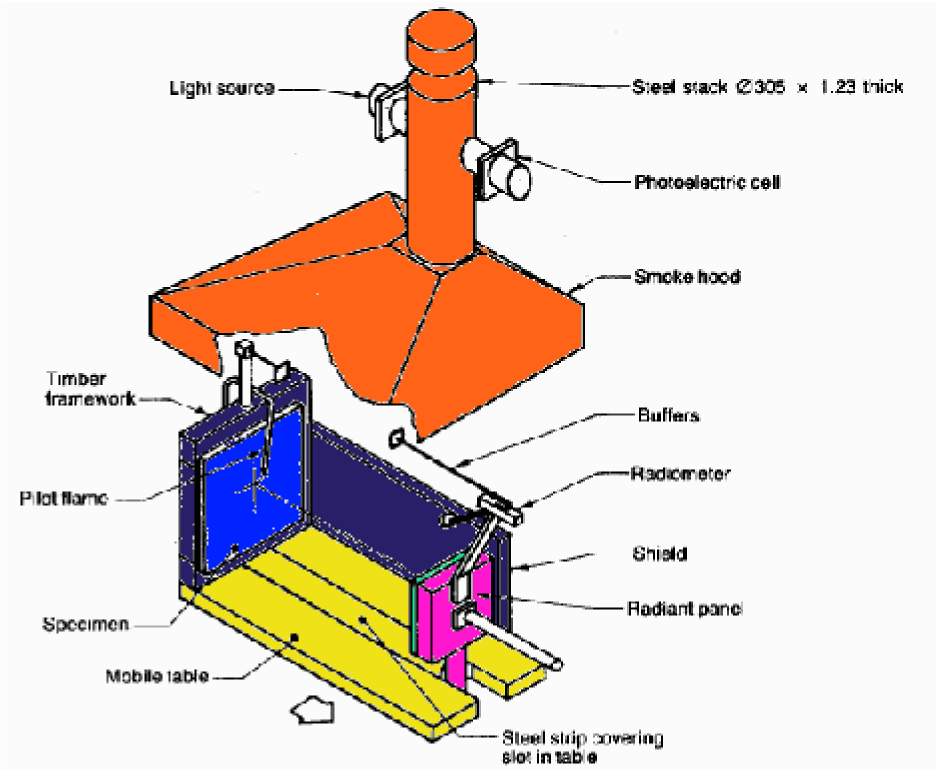

Figure 1: AS 1530 Part 3 Fire Test

RESEARCH AND NEW TESTING METHODS

International research investigating flame spread on room lining materials has included:

EUREFIC (European Reaction to Fire Classification) project (Interscience Communications, 1991) - this was aimed at developing evaluation and classification methods for the fire behaviour of wall and ceiling lining materials in the Nordic countries. Eleven room lining materials were tested at small-scale in the cone calorimeter and at full-scale in a room-corner test. In all these tests, the same materials were fixed to both the wall and ceiling. A classification scheme was recommended which used the time to flashover in the ISO 9705 (ISO, 1990) room fire test. Models using cone calorimeter data were also developed to predict flashover times in the room fire test.

Other research (including that by the author) has focussed on developing mathematical models for predicting the heat release rate history of the developing wall/ceiling fire, based on calculated flame spread and heat release. Karlsson (1993, 1994) at Lund University in Sweden and Quintiere (1993) at the University of Maryland, USA both developed detailed predictive models. The BRANZ research has relied heavily on the Quintiere model. These types of mathematical models all rely on key flammability parameters for the room lining materials as input, such as:

- ignition temperature
- effective thermal inertia
- heat of combustion
- heat of gasification
- lateral flame spread parameter
- minimum temperature for flame spread

These input parameters can be measured or derived using small-scale fire test results from the cone calorimeter (SA, 1998) and the LIFT (ASTM, 1990) apparatus. Initially, recent research has concentrated on attempting to predict the results of the ISO 9705 (ISO, 1990) full scale room corner fire test, which uses a room 2.4 x 3.6 x 2.4 m high with a single doorway opening of 0.8 x 2.0 m high. A gas burner is placed in the corner of the room (opposite the wall with the door opening). In this test, the lining material is fixed to three walls and the ceiling, and the burner is operated at 100 kW output for the first 10 minutes of the test, and if room flashover does not occur the output is increased to 300 kW for the next 10 minutes. For this particular size of room, flashover generally occurs when the total heat release from the fire reaches ~1 MW. Model predictions to date have generally been very successful for `well behaved' materials and less successful for `poorly behaved' materials (ie those that melt or delaminate easily).

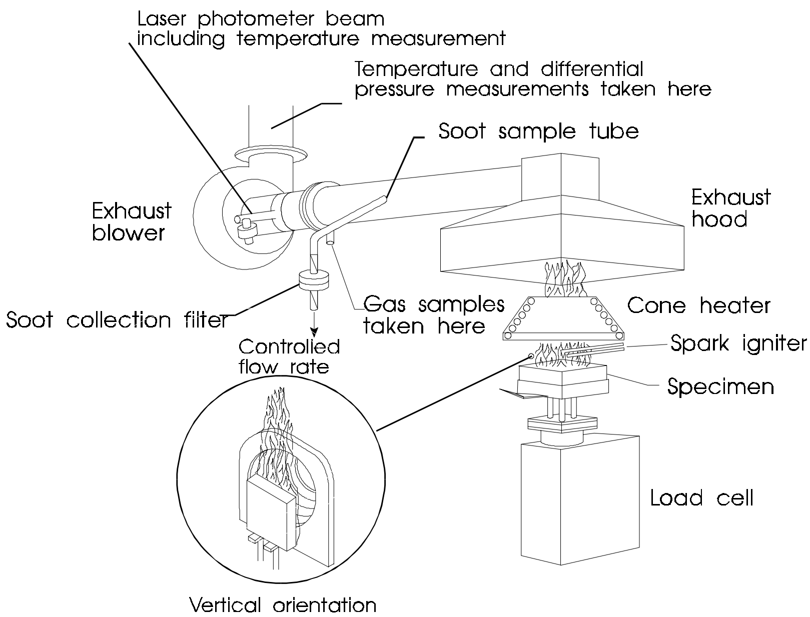

Figure 2: Cone Calorimeter Apparatus

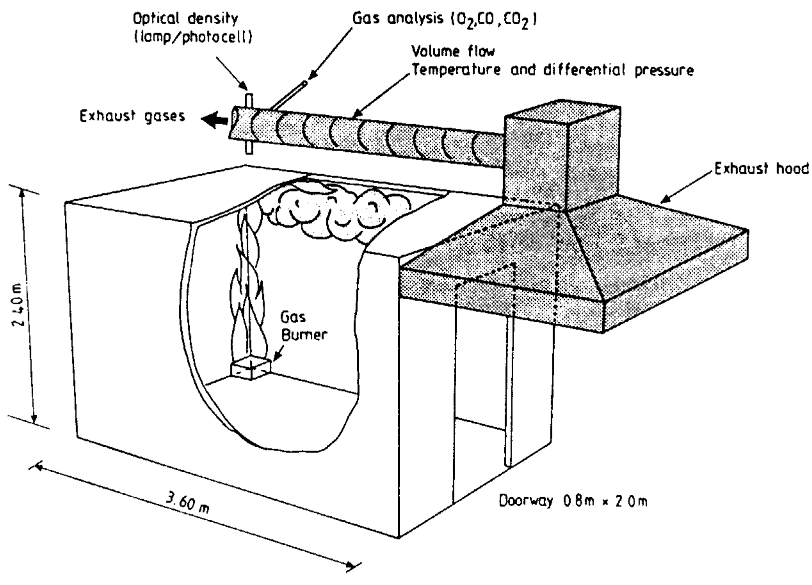

Figure 3: ISO 9705 Room Fire Test

THE PERFORMANCE APPROACH

A performance-based building control system provides opportunity for a detailed fire engineering assessment of appropriate materials for interior linings.

From the Building Code of Australia (ABCB, 1996) -

Objective C01 The Objective of this Section is to-
(b) safeguard occupants from illness and injury while evacuating a building during a fire;

Functional Statement CF2 A Building is to be provided with safeguards to prevent fire spread -
(a) so that occupants have time to evacuate safely without being overcome by the effects of fire;

Performance Requirement CP4 A material and an assembly must, to the degree necessary, resist the spread of fire to limit the generation of smoke and heat, and any toxic gases likely to be produced, appropriate to-

(a) the evacuation time; and
(b) the number, mobility and other characteristics of occupants; and
(c) the function or use of the building; and
(d) any active fire safety systems installed in the building.

Therefore a building designer may meet these performance requirements by choosing to select building materials with interior finishes meeting the appropriate AS 1530.3 spread of flame and smoke developed indices given in the deemed to satisfy provisions. Alternatively they may use an accepted engineering tool to show that hazardous conditions will not occur in the building, or at least will not occur over the time frame required for escape.

Ideally, the engineering tool should not just be a predictive tool for the likely outcome of a standard full-size test such as ISO 9705 (ISO, 1990), but a tool which will account for the dimensions of the building/room being considered, the available ventilation, the configuration of lining materials (ie different materials on the wall, ceiling and floor), and even accounting for the effect of a sprinkler system, if present. The acceptance of the results of the simulation would most sensibly use tenability criteria such as:

- radiative/convective heat exposure to occupants
- concentrations of combustion gases such as CO, CO_2, low O_2, HCN etc
- visibility distances on escape routes.

AN ENGINEERING APPROACH

A computer fire model (known as BRANZFIRE) has been developed at the Building Research Association of New Zealand (BRANZ) which is intended to aid in the assessment of fire hazard of room lining materials, in a manner described in the previous section. The software runs under Microsoft Windows on an IBM compatible PC running Windows 95 or later.

The program takes small-scale fire test data from a cone calorimeter and LIFT apparatus to determine flammability parameters that are input into a combined fire growth, flame spread and room zone model. Many existing fire zone models do not account well (or at all) for the ignition and burning of wall and ceiling lining materials, and consequently they may underestimate the actual rate of fire development and hazard in cases where combustible room linings are present.

Figure 4: Software Introductory Screen

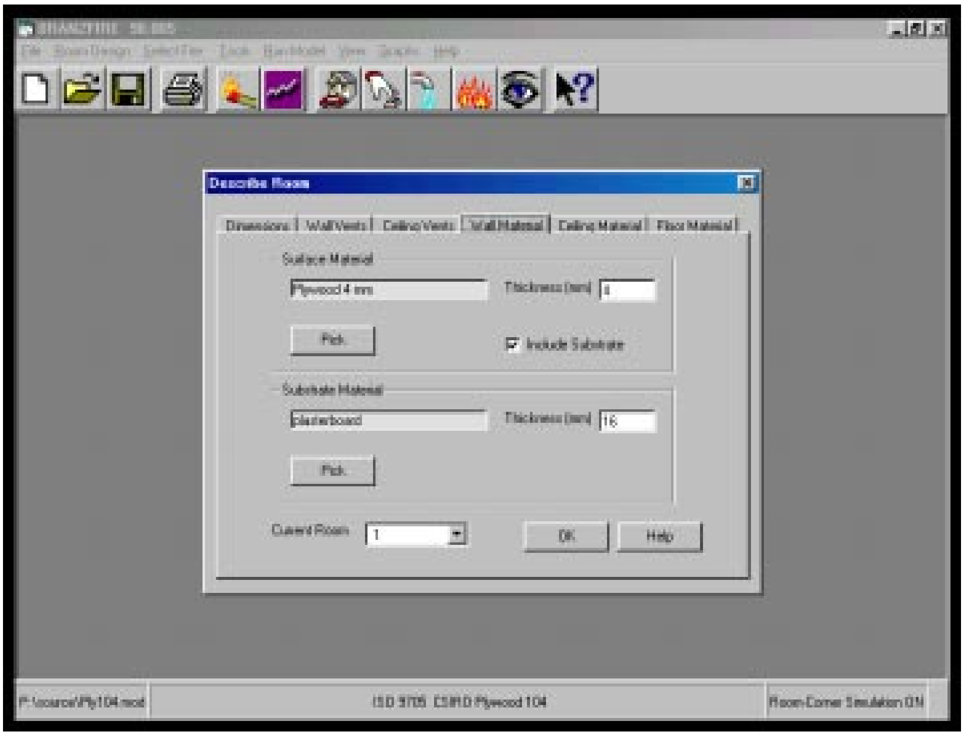

Figure 5: Specification of Wall Lining

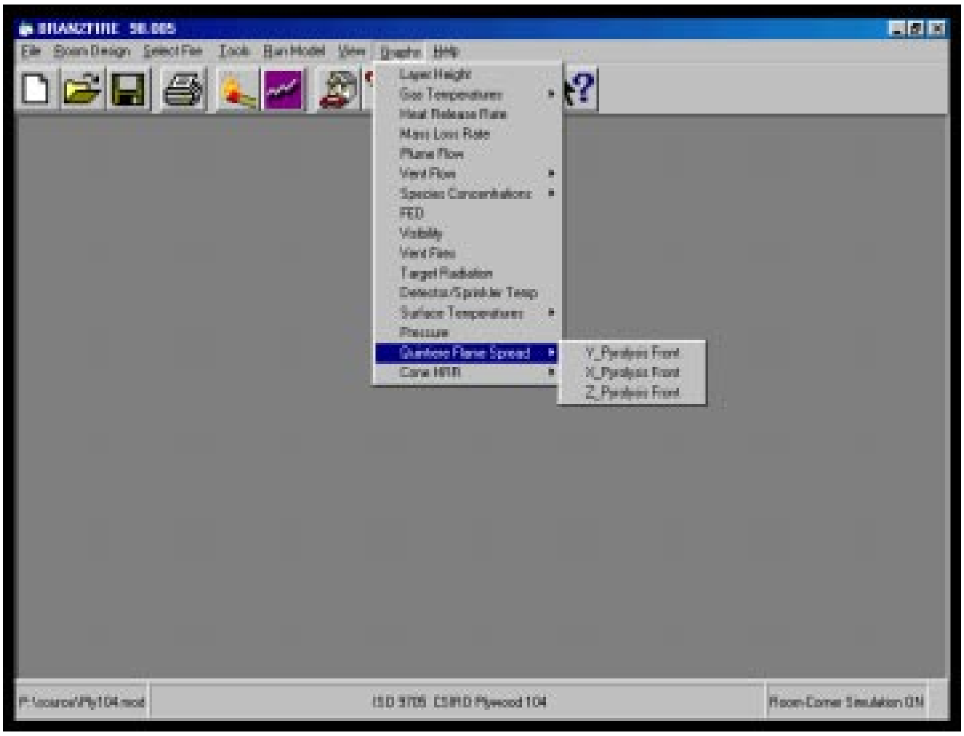

Figure 6: Output Graphs Available

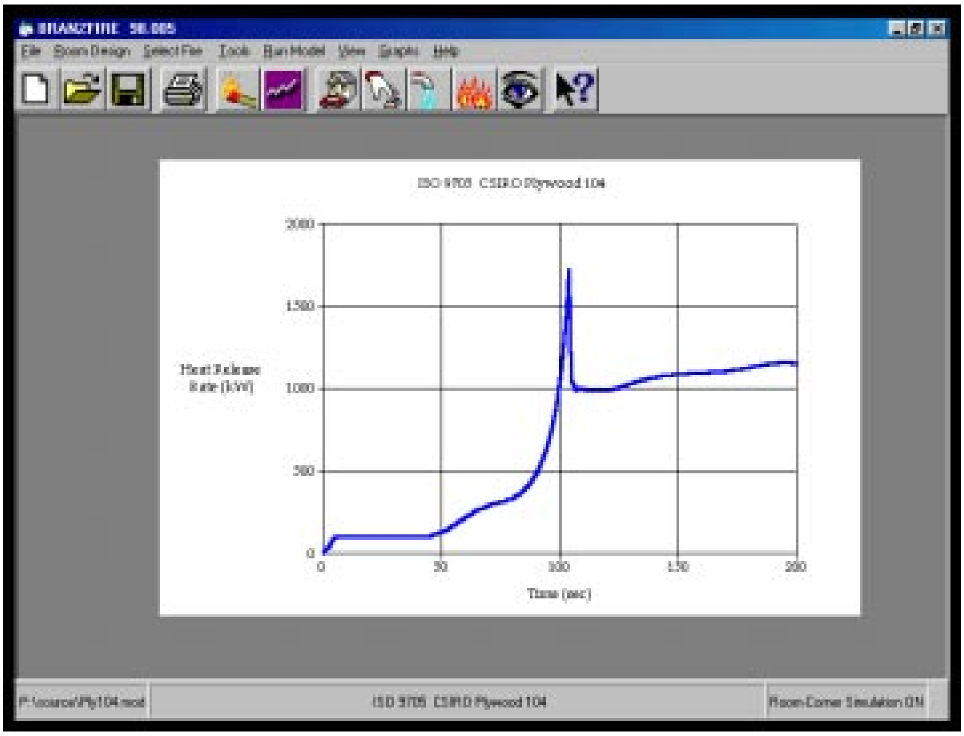

Figure 7: Predicted Heat Release Rate Graph

Determination of Properties of Lining Materials

Each room lining material is required to be tested in a cone calorimeter at a minimum of three different external heat fluxes (the more the better). The ignition times are then correlated (by the BRANZFIRE software) following the method of Grenier and Janssens (1997). This provides an estimate of the ignition temperature and the effective thermal inertia of the material. The average heat of combustion and heat of gasification are also estimated from the slope of the linear regression line through a plot of the peak heat release rate versus the externally applied heat flux (in the test).

Flame Spread and Fire Growth Calculations

The flame spread and fire growth calculations are based on a model developed by Quintiere (1993) with various modifications. Ignition of the wall lining is predicted based on a specified gas burner ignitor in the room (of specified dimensions, heat output, and location in the room). Direct ignition of the ceiling is also considered to allow for wall and ceilings of different materials to be simulated.

Following ignition of the wall, upward flame spread on the wall and beneath the ceiling and along the wall/ceiling intersection is calculated. Opposed flow flame spread (if any) on the wall and down from the ceiling is also determined. Some key points of interest about the model include:

- using actual heat release rate data from a cone calorimeter for the lining materials and applying a correction based on the predicted external heat flux at each time step in the simulation.
- the location of the ignition source (burner) can be varied (room centre, against a wall or in a corner), with the calculated heat flux exposure to the wall and ceiling changing in each case.

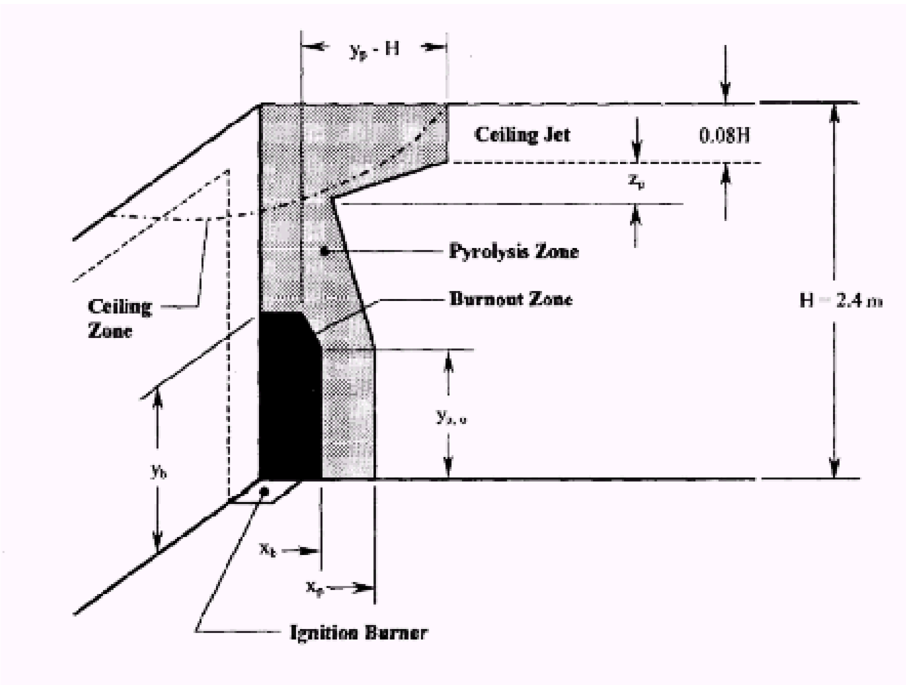

Figure 8: Features of Quintiere's Growth Model (Dillon, 1998)

Zone Model Calculations

The implementation of the zone model in BRANZFIRE has many similarities with the CFAST model. Conservation of mass and energy leads to a set of first order differential equations which allow the upper layer volume, upper and lower layer temperatures, and the pressure equation to be solved over time. The form of the equations is as described by Peacock et al (1993) for the CFAST model.

BRANZFIRE (version 98.005) is a multi-compartment fire model with the mass flow of air and hot gases through the wall vents driven by buoyancy. Bernoulli's equation is used to calculate the flows. The natural vent flow routines developed by Cooper and Forney (1990) from the CCFM.VENTS computer code are used.

Heat transfer between room surfaces is considered by use of a four-wall radiation exchange algorithm using the method described by Forney (1994). This allows the ceiling, walls and floor to transfer radiation independently. Conduction to walls is calculated using an implicit finite difference method, with walls and ceiling able to be specified as a one or two layer system.

The zone model uses the calculated fire heat release rate (from the flame spread and fire growth calculations) to predict the room gas temperatures, pressure, position of the smoke layer height, concentrations of carbon monoxide and carbon dioxide, visibility in smoke, fractional effective doses and room surface temperatures as well as other physical parameters. The development of a hot layer results in heat transfer to the room lining materials causing them to pre-heat prior to ignition and the advance of a pyrolysis front. This pre-heating effect would be expected to increase the rate of flame spread and overall fire growth in the room.

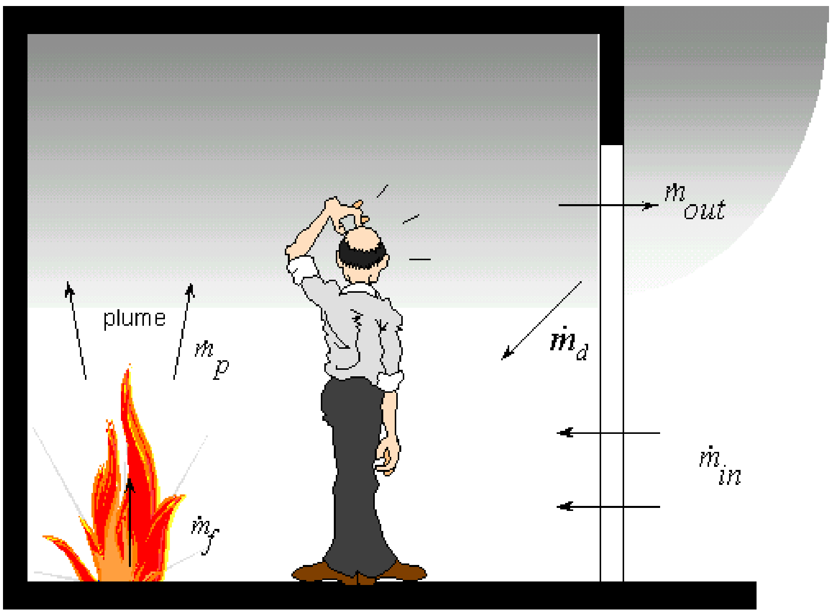

Figure 9: A Zone Model - Conservation of Mass and Energy in Room

Verification and Validation

The process of `proving' the performance of a predictive engineering model or tool such as the BRANZFIRE software is not an easy or straightforward process. It can be more of a case of carrying out a sufficient number of studies comparing the results of the computer simulation with experimental data, and developing a level of confidence in the ability of the model to provide realistic assessments.

Validation studies carried out to date would indicate that agreement with experimental data is often very good particularly for relatively well behaved materials including many wood products. Agreement is not as good for materials that melt easily or delaminate and further study of how to best model these types of materials is needed (eg recent research by Dillon (1998)). One also needs to consider the accuracy and limitations of the experimental data; for example, Figure 10 shows how the prediction is higher than the experimental result at the start of the test. This is typical of most simulations and is due to a time lag in recording the true heat release rate in the room (100 kW before ignition of the wall lining).

As incorporating new algorithms extends the capability of the model, additional comparisons with experimental data will also be needed. At the current time comparison of BRANZFIRE predictions compared with experimental data can be found in the following references: Wade (1996), Wade and Barnett (1997), and Wade et al (1997). It is believed that the BRANZFIRE model could be used for predictions of many wood-based products at the current time provided results are carefully scrutinised and adequate small-scale cone calorimeter data is available.

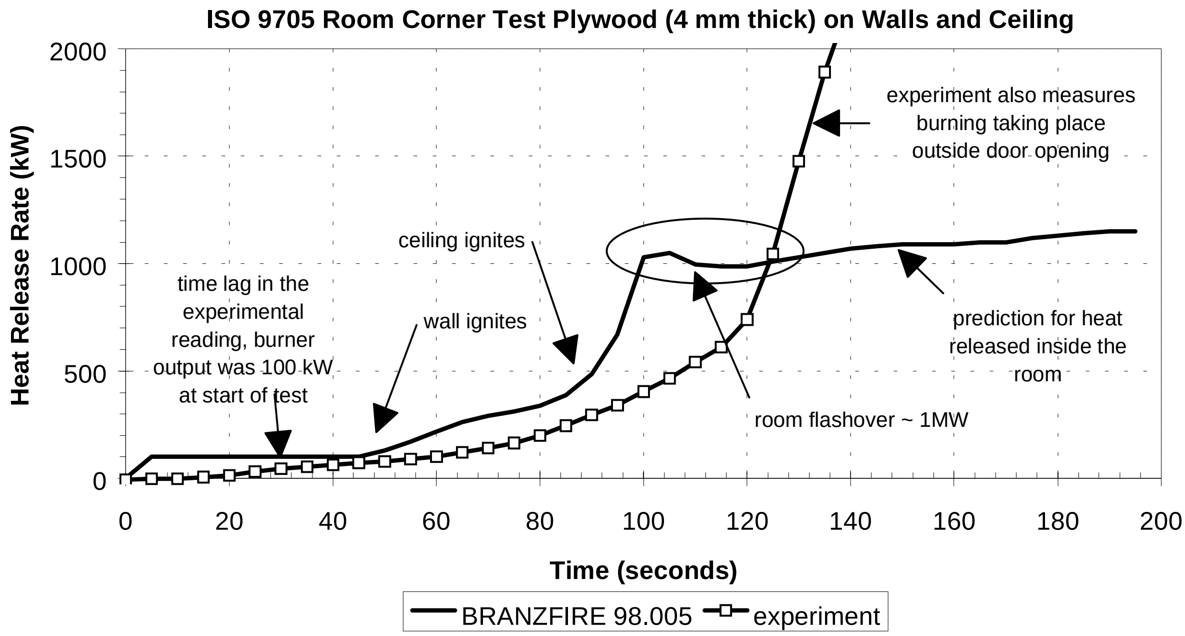

Figure 10: Comparison with Experiment for Plywood

Future Developments

The BRANZFIRE model and software development is continuing at BRANZ and intended future work will include:

- an extension of the general capability of the (zone) model to include post-flashover fires
- including flame spread across floors in addition to existing wall/ceiling flame spread
- modelling ignition of linings in adjacent rooms (including room-corridor tests)
- inclusion of alternative lining ignition sources (eg furniture models).

CONCLUSIONS

This paper gives an indication of how engineering models and tools will be used in the future, to aid in the fire hazard assessment of combustible room lining materials. The tools potentially provide much better predictions of likely full-scale behaviour of materials in configurations not able to be individually tested, and with a much stronger theoretical basis than selecting materials based on their stated small-scale fire test indices. The BRANZFIRE model is one software program that is currently under development for this purpose.

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