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Impact of Combustible Linings in Large or Tall Compartments

by

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Notice

Abstract

For aesthetic reasons, architects or owners often want to use exposed wood products in large, tall open structures and in atria where non-combustible materials are generally specified by building codes. In order to demonstrate that such applications can be made safe provided extra fire safety measures are taken, fire protection engineers often must employ computer modelling or full-scale fire-testing. Unfortunately though, the use of wood products in many of these projects is not pursued because there is not sufficient time, commitment or resources available to undertake the lengthy and expensive analyses required to get approval for the non-compliant designs.

This study was initiated to examine the impact on fire safety presented by combustible ceiling and/or wall coverings as the floor area and ceiling height of both sprinklered and unsprinklered compartments increase. It was proposed that existing or newly developed fire models could be employed to predict under what circumstances wood linings can be used safely in tall and/or large-area compartments. It was further suggested that simple design criteria could be developed for the use of the design community or, possibly, for inclusion in building codes.

A literature review identified two computer fire models that were potential candidates for use in this project: BRANZFIRE and Fire Dynamics Simulator (FDS). BRANZFIRE is a zone model; that is, in the event of fire, it divides a room (atrium) into two zones: a hot upper layer and a cooler lower layer. While is was found that BRANZFIRE is ideally suited for predicting fire development involving combustible wall and ceiling linings in small rooms, its predictions in large rooms, such as atria, are poor. The two zone approximation is simply too coarse.

FDS is a computational fluid dynamics model in which the room (or atrium) of fire origin can be broken up into a large number of cells (potentially thousands), rather than just two zones. Although this was promising, it was learned that recent attempts by others to use FDS to model upward flame spread on combustible walls had not been successful. The pyrolysis and combustion models in FDS are not up to the challenge.

Attempts made to attract a student at Carleton University, where considerable computing resources are available, to develop improved pyrolysis and combustion models for use in FDS have not been successful. Coupled with the reduced funding available for General Revenue projects, a decision was taken to terminate work in this project.

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1 Objectives

To characterise the contribution of combustible wall and ceiling linings to fire growth in tall and/or large-area compartments.

To develop criteria or a methodology to predict under what circumstances wood linings can be used safely in tall and/or large-area compartments.

2 Introduction

For aesthetic reasons, architects, engineers or owners often want to use exposed wood products in large, tall open structures and in atria where non-combustible materials are generally specified. For example, recently, during the design of the Vancouver Convention Centre Expansion Project (VCCEP), the B.C. government insisted that wood products be “showcased”. As a consequence, even though the Vancouver Building By-Law (VBBL) required the ceiling to be non-combustible, architectural (i.e. non-load-bearing) suspended ceilings constructed of glulam or parallam slats were to be constructed in a large Ballroom on the 4th storey and in pre-function areas on the 4th and 5th storeys. In order to demonstrate that this was safe, fire protection engineers employed computer modelling to show that the sprinkler system coupled with the high overhead space ensured that the wooden slats could not be ignited by severe but credible fires that could develop in these areas.

In other design projects, where wood was to be used as a room lining in a noncompliant fashion, full-scale fire tests were conducted to demonstrate that the proposed design was safe. For example, tests were conducted to simulate the contribution of wooden walls to fire growth in tall exhibition modules built for Expo 86 in Vancouver. The results demonstrated that the high overhead heights and large floor areas ensured that flame spread on the walls did not cause untenable conditions to develop within the modules.

The above two examples involved high profile projects in which there was strong motivation to use wood and sufficiently generous budgets available to undertake expensive computer modelling or fire tests to demonstrate a fire-safe design. Practicing fire protection engineers have told FPInnovations – Forintek Division scientists that, in many projects, there is not sufficient time, commitment or resources available to undertake the lengthy and expensive analyses required to get approval for non-compliant designs.

This study was initiated to examine the impact on fire safety presented by combustible ceiling and/or wall coverings as the floor area and ceiling height of both sprinklered and unsprinklered compartments increase. It was proposed that simple criteria be developed that would allow the design community to predict under what circumstances wood linings can be used safely in tall and/or large-area compartments.

3 Background

In Project 3638, “Fire Performance of Interior Finishes, Room Linings and Structural Panel Products”, which terminated in March 2006, an analysis of the contribution of room linings to early fire growth was undertaken. Part of this analysis included fire tests on wooden wainscoting, wall panelling and ceiling panelling in the room-corner facility defined in ISO 9705. This facility is the size of a small bedroom: 2.4 m (width) x 3.6 m (depth) x 2.4 m (height). Canadian and international requirements for the fire performance of combustible room linings are based on standard fire tests that have been calibrated to give results commensurate with those obtained in ISO 9705. In other words, international requirements for the fire performance of combustible room linings are based on results generated in a small room. Although this practice is appropriate for regulating room linings in highly compartmented buildings (apartment buildings and many office buildings), it is clearly not appropriate for regulating the performance of room linings in tall and/or large-area compartments. Unfortunately very little research has been undertaken that would provide the knowledge required to develop such regulations.

4 Staff

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5 Proposed Approach

Originally this was to be a two-year project to be completed by March 2008. The original work plan proposed in 2006-07 was as follows:

- By August 2006, a literature review of the fire performance of combustible linings in tall and/or large-area spaces was to have been completed.
- By November 2006, mathematical models to predict flame spread on linings in large spaces were to have been identified or developed.
- By February 2007, computer modelling was to have been undertaken to identify where wood linings can be safely used.
- By October 2007, fire experiments were to have been conducted to validate the model predictions.
- By December 2007, design criteria were to have been developed for submission to building code communities.
- By March 2008, a scientific paper was to have been written summarising findings in the project.

By the beginning of 2007-2008, the project was behind schedule, so the timeframe for undertaking computer modelling to identify where wood linings can be used safety was extended from February 2007 to June 2007. The schedule for the rest of the work was unaltered.

Unsuccessful attempts at identifying a model to undertake the work put the project very far behind schedule in 2007-2008. Consequently the project was extended for one year with the following work plan for 2008-2009:

- By June 2008, computer modelling was to have been undertaken to identify where wood linings can be safely used.
- By October 2008, fire experiments were to have been conducted to validate the model predictions.
- By December 2008, design criteria were to have been developed for submission to building code communities.
- By March 2009, a scientific paper was to have been written summarising findings in the project.

6 Results and Discussion

6.1 Progress in 2006-2007

A review of the literature was undertaken and the computer model BRANZFIRE (Wade, 1997) was identified as a potential candidate for use in this project. BRANZFIRE is a multi-room zone model; that, in the event of fire, divides each room in a building into two zones: a hot upper layer and a cooler lower layer. It has been designed to address flame spread along combustible walls and across a combustible ceiling. BRANZFIRE output includes but is not limited to: gas layer temperatures, vent flows, pressure, room surface temperatures, layer height, visibility and fractional effective dose estimates.

BRANZFIRE has been successfully used to simulate ISO 9705 room-corner fire tests as well as fires involving contents in a small compartment. In ISO 9705, the test specimen lines the walls and the ceiling of a room with floor dimensions 2.4 m by 3.6 m and height of 2.4 m. A burner in a back corner, opposite an open door (0.8 m by 2.0 m), burns at 100 kW (equivalent to a fire involving a full waste-paper basket) for 10 minutes, and the rates of heat release and flame spread over the combustible linings is observed. If flashover (i.e. full involvement of the linings) does not occur during the first ten minutes of the test, the burner output is increased to 300 kW (equivalent to fire involving a small upholstered chair) for another 10 minutes. The primary purpose of the test is to observe how long it takes for the entire interior finish to be involved in fire. This time is referred to as the time to flashover. BRANZFIRE uses fire property data obtained from cone calorimeter tests (ISO 5660) as input. This made BRANZFIRE particularly appealing as Forintek had arranged to have Southwest Research Institute (SwRI) conduct both cone calorimeter tests (ISO 5660) and room-corner tests (ISO 9705) on several wood products during 2005-2006. The wood products were white pine boards, white oak boards, OSB, Douglas fir plywood and FRT Douglas fir plywood. This meant that model validation for small-scale scenarios could be carried out.

It was, however, not clear whether the model could be applied to large area or tall compartments. To explore this possibility, a 90 day trial version of BRANZFIRE (version 2004.3) was downloaded from the BRANZ (New Zealand) web-site free of charge.

BRANZFIRE was found to be user friendly and, on the face of it, well suited for the objectives of this project as it can simulate flame spread along combustible wall and ceiling linings in tall and/or large-area compartments. The supporting documentation, however, does not include validation experiments for rooms with floor dimensions larger than 2.4 m x 3.6 m and heights greater than 2.4 m; that is, larger than the ISO 9705 room-fire apparatus. The principal developer of BRANZFIRE, Colleen Wade, was contacted to learn more about the validation of the model. She mentioned that there had been unpublished validation exercises conducted for larger rooms and the model appeared to work well. It was agreed that Ms. Wade and Dr. Mehaffey would discuss the model in more detail at ISO meetings November 4-9, 2006 in Kyoto, Japan.

During the ISO meetings it was learned that fire tests had been conducted in Finland in 1991 in a room 4.9 m high, 9.0 m wide and 6.75 m deep with a single opening of 2.0 m by 2.0 m. This is notably larger than the ISO 9705 room. A burner was located in a corner opposite the door and was programmed to have heat output of 100 kW for 10 minutes, 300 kW for the next 10 minutes and 900 kW for the last 10 minutes. The product to be tested lined the walls and ceiling of the room. Tests were conducted on four products: 12 mm birch plywood, 16 mm fire-retardant particle board, textile wall-covering on 12 mm gypsum board and PVC wall carpet on 12 mm gypsum board. Subsequently BRANZFIRE was employed to simulate the flame spread along these combustible wall and ceiling linings. BRANZFIRE did a good job of predicting the results of the tests conducted on the fire-retardant particleboard and on the two wall coverings on gypsum board. However, it did a poor job of simulating the performance of the 12 mm birch plywood and, in fact, predicted flashover occurred much earlier than observed in the tests.

6.2 Progress in 2007-2008

J.R. Mehaffey delivered a paper co-authored by J.P. Huczek and M.L. Janssens of Southwest Research Institute (SwRI) during the conference *Interflam 2007* in London, UK September 3-5 (Mehaffey, 2007). A brief discussion of the paper follows:

- ***Motivation - Forintek:*** FPInnovations – Forintek Division is often asked by the industry when wood panelling is permitted in our export markets as a wall lining, a ceiling lining and as wainscoting. The question is challenging because both building code requirements and fire test methods for room linings vary from country to country. In principle, wood products must be subjected to the single-burning item test (SBI or EN 13823) in Europe; the cone calorimeter test (ISO 5660) in Japan, Australia and New Zealand; and the Steiner tunnel test (ASTM E 84) in North America.
- ***Globalisation:*** As globalisation intensifies, there is much interest internationally in comparing and correlating the performance of products as assessed by the different test methods used in various jurisdictions in order to facilitate trade. The room-corner test (ISO 9705) is proving useful in this regard. Although expensive and time-consuming to run, of all the test methods used to quantify the performance of lining materials, it is the most representative of real-world fire scenarios. Consequently the room-corner test has become a reference scenario whereby the results generated in other tests can be understood. In fact, as countries move towards harmonisation of standards, there is a tendency to base product acceptance on performance in either a national fire test method or in the ISO room-corner fire test. Already, the European Union, Japan, Australia and New Zealand accept room-fire tests as one way of demonstrating compliance with building regulations. For products such as wainscoting, the room-corner test may be the only standard test method that can give a meaningful indication of fire performance in real life scenarios.
- ***Motivation - SwRI***: While Forintek was drawing up a plan to have several common wood products subjected to a variety of international fire tests, it was learned that SwRI had a somewhat related research project underway. SwRI was generating fire test data to validate models that could be used to predict performance in the Steiner tunnel, SBI and room/corner tests based on the results of cone calorimeter tests. Their plan was to test eight different materials in the cone calorimeter, the tunnel, the SBI apparatus and the room/corner facility. Only two of the eight materials in the SwRI program were wood products. The objective of the SwRI program was similar to Forintek's, except that the focus of Forintek's project was on wood products.
- ***Collaboration***: An agreement was therefore made with SwRI to conduct tunnel tests, cone calorimeter tests, single-burning-item tests and room-corner tests on several wood products. The wood products were white pine boards, white oak boards, OSB, Douglas fir plywood and Fire-retardant treated Douglas fir plywood. Although not part of the SwRI Project, two series of non-standard room-corner tests were conducted for Forintek: one in which the walls were lined with wood paneling and the ceiling with gypsum board; and one in which the walls had wainscoting on the lower part and gypsum board on the upper part of the walls and on the ceiling.

- ***Results - Wainscoting***: Although the paper summarised and analysed the data generated for wood products in all of these tests, particular attention was given to the results of the non-standard room-corner tests involving wainscoting. Flashover did not occur in any of the tests involving wainscoting, be it in the first ten minutes of the test when the burner's rate of heat release is set at 100 kW nor in the second ten minutes when the burner rate of heat release is increased to 300 kW. Presumably these findings will have implications for the use of wainscoting in many new applications.
- ***Other Uses for the Data:*** The data generated in this collaborative venture with SwRI are proving useful in the development of mathematical models for use in jurisdictions where performance-based design is permitted. The data are useful as input for the models or for validation of the model predictions.

In recent years, papers presented by the wood industry at fire conferences have typically addressed fire resistance issues and there were once again several papers of that type at *Interflam 2007*. Interestingly, though, there were also a number of papers addressing the flammability of wood-based products, particularly when used as interior lining. As two of these papers were of interest for this project a brief summary of them follows:

- "Flame spread on a solid wooden ceiling", V. Stenstad (Norway) and B. Karlsson (Iceland): An experimental and theoretical study was reported in which flame spread along a solid wood ceiling in an open, above-ground parking garage was investigated. The fire scenario involved a simulated car fire in the absence of sprinklers. It was found that if the wooden ceiling was planar, flame spread was confined to an area close to the ignition source. Consequently, a well-ventilated car park with a plain solid wooden ceiling does not constitute an immediate threat to evacuating people or to firefighters attempting to suppress the fire. Such a multi-storey structure is now under construction in Norway.
- "The influence of floor coverings on room fires", P. Johnasson, Sweden: After flashover, all combustible materials become involved in a fire, including combustible flooring materials. This project looked at fires originating under beds in old-age homes. It was found that the choice of flooring material had a significant impact on the time to flashover, amount of smoke produced and total heat production. Several commercially available synthetic floor coverings labelled as vinyl (PVC) and polypropylene performed particularly poorly, while wood products performed better.

On May 15, 2007, four researchers from VTT (Technical Research Centre of Finland) visited the Fire Research Group in Ottawa: Dr. T. Hakkarainen (fire), Dr. A. Kevarinmäki (wood construction), Dr. J. Mali (wood products) and Dr. A. Nurmi (preservatives). The discussions were wide ranging and touched upon the fire-resistance of wood assemblies, the flammability of wood linings and strength reductions of fire-retardant treated wood. Dr. Hakkarainen mentioned some VTT experiments conducted in large rooms a number of years ago in which the contribution of wooden room linings to fire growth was assessed. The rooms were 4.9 m high, 9.0 m wide and 6.75 m deep with a single opening of 2.0 m by 2.0 m. These were the experiments Ms. Wade (BRANZ) had used to validate BRANZ. She also provided the details of the European Union's classes of reaction-to-fire performance (flammability) of room linings and the CWFT decision taken whereby most wood products can be *Classified without Further Testing (CWFT)*. These latter details will prove useful when assisting members with market access in Europe.

After further experience using BRANZFIRE, it was noted that BRANZFIRE was structured to model scenarios in which the walls are all lined with one material, but the ceiling can be lined with a different material. As such BRANZFIRE does a good job in simulating the results of ISO 9705 tests run at SwRI in which the walls and ceiling were lined with a wood product or the walls were lined with a wood product and the ceiling with gypsum board. However, the model is not structured to deal with wainscoting. According to the model developers, BRANZ in New Zealand, the model could be restructured to address wainscoting. However this would require funding and the results of the tests with wainscoting conducted at SwRI are convincing enough: wainscoting does not present a fire problem.

However, BRANZFIRE does not do a good job in predicting fire spread along wooden room linings in large area or tall rooms. This conclusion had already been drawn by BRANZ researchers when they tried to simulate fires in larger rooms, such as those used in the VTT study. BRANZFIRE predicts that flashover occurs much earlier than observed in tests. The basic problem is that the two-zone assumption breaks down. In large-area or tall rooms it is simply not possible to assume the hot smoke layer is at a uniform temperature throughout. The layer is hotter near the corner or wall where the fire starts and cooler in more distant locations. Clearly a more detailed model is required for this project.

Fire Dynamics Simulator (FDS) developed by NIST in the USA (McGrattan, 2005) was identified as being a potentially better model for simulating fires involving wainscoting in small rooms or fires involving combustible wall and/or ceiling linings in large areas or tall compartments. FDS is a computational fluid dynamics model in which the room of fire origin can be broken up into a large number of cells (potentially thousands), rather than just two zones. Once again data from the cone calorimeter provides the required input data to run the model. On the negative side, FDS requires significant computer resources (and time) to run. To learn more about FDS, Forintek scientists S. Craft and J. Mehaffey participated in a short course for practitioners entitled *Fire Dynamics Simulator and Smokeview* that was offered by Carleton University. During the course it became clear that the Fire Research Group does not have the computer resources required to run FDS simulations of fires involving walls and/or a ceiling in large areas or tall compartments. On the other hand, Carleton University does have the requisite computing power. Consequently the NSERC Chair at Carleton University agreed to assist in identifying a student to undertake simulations using FDS. It was thought that this could become a M.A.Sc. thesis project in 2008-2009.

Since computer modelling with BRANZFIRE did not provide the accuracy needed, a new direction was chosen, namely modelling with FDS. Due to the change in direction, the deliverables for 2007-2008 could not be completed. Consequently a decision was made to extend the project for another year.

6.3 Progress in 2008-2009

An important objective in this project is to predict the rate of upward flame spread over wood products on tall walls. Upward flame spread rates over combustible materials are not only faster than downward or horizontal flame spread rates but also tend to accelerate as the flame moves upward. This makes upward flame spread difficult to model. A recent paper (Kwon, 2007) reported three simulations in which FDS was employed to predict upward flame spread. The FDS predictions were compared with experimental data for upward flame spread on a 0.6 m wide, 5 m high polymethylmethacrylate (PMMA or plexiglass) panel. A brief summary of the three simulations follows:

- In the first simulation, the vertical flame spread experiment over the 5 m PMMA panel was modelled using the default values for FDS input parameters. The thermal decomposition (pyrolysis) of PMMA entails MMA monomer being released at each end of the polymer chains. Consequently a first order Arrhenius equation was used to predict the pyrolysis rate at elevated temperatures. Chemistry in the flame was modelled using a mixture fraction combustion model in which chemical reactions proceed infinitely fast, and the fuel and oxygen cannot co-exist at any point in space. Using these pyrolysis and chemical reaction models as input, the FDS predictions did not exhibit the trends in flame spread seen in the experiments. The flame height was dramatically over-estimated.

- In the second simulation, the gaseous and condensed phases were decoupled to better assess the gas phase calculations in FDS. A steady-state burner 0.6 m wide and 1 m high was simulated at the bottom of the PMMA panel. The rate of heat release was precisely that measured in the experiments when the bottom 1m of the PMMA panel was undergoing pyrolysis. The prediction from this gas burner simulation matched well the flame height in the experiments when the bottom 1 m of the panel was undergoing pyrolysis.
- In the third simulation, an effort to mitigate the over-predicted flame height in the first simulation was made by altering the combustion model built into FDS. The results were better, but the flame height was still over-predicted.

The authors concluded that FDS does not give reliable predictions of the flame height in upward flame spread. This is principally due to the combined effects of the FDS pyrolysis and combustion models.

The pyrolysis of wood products is much more complex than that of PMMA. Nonetheless, although it does not entail a single step chemical reaction, a first order Arrhenius equation has been shown to do a good job in simulating the burning rate in horizontal orientations. The experience of those attempting to model upward flame spread on PMMA suggests, however, that we will need to be very cautious in our assessment of upward flame spread on wood products when using FDS.

Efforts were expended during the first two Quarters to identify a student at Carleton University, where considerable computing resources are available, to undertake the simulations. Unfortunately, all existing students in the Fire Safety Engineering Program had already selected their thesis projects. The newly enrolled students would not be in a position to select a thesis project until the 3rd or 4th Quarter. Coupled with the reduced funding available for General Revenue projects, a decision was taken to terminate work in this project early in the 3rd Quarter.

7 Conclusions

This study was initiated to examine the impact on fire safety presented by combustible ceiling and/or wall coverings in large or tall compartments, such as atria. It was proposed that fire models could be employed to predict under what circumstances wood linings can be used in such compartments without compromising fire safety. Based on this knowledge, it was intended that simple design criteria could be developed for the use of the design community or, possibly, for inclusion in building codes.

A literature review identified two computer fire models that were potential candidates for use in this project: BRANZFIRE and FDS. BRANZFIRE is a zone model: It divides a room (atrium) into two zones: a hot upper layer and a cooler lower layer. While is was found that BRANZFIRE is ideally suited for predicting fire development involving combustible wall and ceiling linings in small rooms, its predictions in large rooms, such as atria, are poor. The two zone approximation is simply too coarse.

FDS is a computational fluid dynamics model in which the room of fire origin can be broken up into a large number of cells, rather than just two zones. Although this was promising, it was also evident that FDS requires more computing power than is available with personal computers. Furthermore, it was learned that recent attempts by others to use FDS to model upward flame spread on combustible walls had not been successful. The pyrolysis and combustion models in FDS are not up to the challenge.

Attempts made to attract a student at Carleton University, where considerable computing resources are available, to develop improved pyrolysis and combustion models for use in FDS have not been successful. Coupled with the reduced funding available for General Revenue projects, a decision was taken to terminate work in this project in the 3rd Quarter of 2008-2009.

8 Recommendations

Although not permitted by building codes, for aesthetic reasons, architects or owners often want to use exposed wood products in large, tall open structures and in atria. This could be both a lucrative market for wood products as well as profitable way to showcase wood products. It is recommended that when resources are available and a good student found, that FPInnovations consider pursuing this subject again in collaboration with the Chair in Fire Safety Engineering at Carleton University.

However the work will be challenging. In small rooms fire dynamics are well represented by two-zone models. Furthermore, the material property data needed as input to predictions of flame spread along combustible walls in small rooms can be generated using the cone calorimeter. However in large and/tall rooms, the two-zone assumption breaks down and the open space must be divided into numerous cells, as is done in FDS, in order to generate an accurate representation of fire dynamics. Combustible walls and ceilings therefore experience very large gradients in radiant heat flux. To predict flame spread in such scenarios it will first be necessary to develop a more fundamental description of pyrolysis and combustion than can be generated using the cone calorimeter. It is this problem that must be tackled first before further progress can be made in predicting flame spread in tall or large rooms.

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