A Model for Predicting Heat Transfer Through Noninsulated Unloaded Steel-Stud Gypsum Board Wall Assemblies Exposed to Fire

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Abstract
With the advent of performance-based codes and performance-based fire safety design options, validated fire-resistance models have become essential. In this paper, a one-dimensional heat transfer model for steel-stud, noninsulated, unloaded gypsum board protected wall assemblies is presented. Also presented are a comparison between temperature predictions and measured temperatures at different locations in gypsum board wall assemblies as well as a comparison between the predicted and measured fire-resistance ratings. The model, which predicts slightly conservative fire-resistance ratings compared to the experimental measurements, is appropriate for most fire safety engineering applications. Considerations for further model development are identified.

Introduction
To maintain building integrity and to reduce fire spread from the compartment of fire origin to adjacent compartments, building codes normally require each compartment in a building to be separated from the remainder by continuous, fire-rated barriers, such as walls and floors. A fire in its postflashover stage can spread beyond the compartment of fire origin should its boundaries fail. Rated fire barriers are designed to control the fire within the compartment of fire origin for an extended period of time, which is usually specified, to allow safe egress of building occupants and to provide adequate time for the fire service to extinguish the fire before it can spread to other compartments. For this reason, rated fire barriers play an important role in building and life safety, and in the codes and standards which regulate such safety. The extent to which these barriers provide that protection is measured as the fire-resistance or fire-endurance rating, determined on the basis of full-scale fire testing.

Since full-scale tests to measure the fire resistance of walls and floors are expensive and time consuming, validated models have been advocated as a replacement means to predict performance. These models have already proven to be an economical way to determine fire-resistance ratings for solid structural elements, but they have not yet become commonplace for assemblies made up of diverse components, such as insulated, membrane-protected partitions.

Because of the potential for a multitude of materials and design arrangements
for assemblies, such as gypsum board protected stud walls, architects and fire safety engineers have, in recent years, requested a means of determining fire-resistance ratings on an engineering basis, using mathematical models. With the advent of performance-based codes and performance-based fire safety engineering, validated fire-resistance models have become essential. For example, in support of performance-based codes, the National Research Council Canada (NRCC) is developing a Fire Risk Evaluation and Cost Assessment Model (FiRECAM)\(^1\) for various occupancies, such as homes and offices. In FiRECAM, a submodel to predict the performance of all types of fire barriers is necessary.

This paper summarizes the development and validation of an engineering model for predicting the fire resistance of noninsulated and unloaded steel-stud wall assemblies. This is a first step in providing designers with calculation methods for fire resistance and serves as one input for FiRECAM's submodel on fire barriers. Since unloaded, noninsulated gypsum board on steel-stud walls are commonly used as fire barriers in both mercantile and office occupancies, this model also has immediate practical value for fire safety engineers.

Studies on predicting heat transfer through wood-stud wall assemblies exposed to fire have previously been carried out\(^2,3\). In modeling wood-stud walls, the wood studs, unlike steel studs, are normally spaced at 400 mm o.c., and, when they ignite, they provide additional heat to the wall cavity. As such, wood-stud walls must be modeled two-dimensionally for heat transfer purposes.

For unloaded steel-stud walls, on the other hand, the studs are normally spaced further apart, at 600 mm o.c. They are thin (0.46 mm thick) and they add no extra heat to the wall cavity. As such, the effects of the steel studs on heat transfer through a gypsum board protected stud wall can be considered insignificant, allowing the use of a one-dimensional engineering model to calculate fire resistance for such assemblies.

For unloaded wall assemblies, a recent study\(^4\) has shown that failure is predominantly due to heat transfer through the assembly. Thus, heat transfer models can be used to safely predict the fire resistance of such unloaded wall assemblies. This paper deals with the development of a model for predicting one-dimensional heat transfer through noninsulated, unloaded, steel-stud wall assemblies exposed to fire. Models for predicting the heat transfer through insulated; unloaded and insulated; and noninsulated, loaded steel-stud walls are also being developed at NRCC. Results will be published in the near future.

In this study, the heat transfer equations that determine the temperature history across the wall assembly from the fire side to the ambient side were programmed, and the program was used to predict the temperature distribution for a given time-temperature relationship for the fire and for the gypsum board thicknesses of the two wall assemblies modeled. The wall assemblies were also tested under standard fire-test conditions, and the measured and predicted temperature results were compared. Considerations for further model development are identified.