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A basis for using fire modeling with 1-D thermal analyses of partitions to simulate 2-D and 3-D structural performance in real fires

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Abstract

Computer fire models for simulating compartment fire environments typically require a mathematical formulation that couples the thermal response of the gases that fill the compartment and the thermal response of compartment partitions. The fire environment characteristics calculated by such models can be used to provide input, via thermal boundary conditions, to an uncoupled thermal-structural computer model for simulating and evaluating the combined thermal/structural performance of the partitions. The objective of such a combined analysis would be to determine, through analysis, the structural fire resistance of a partition design. Depending on the particular partition design of interest, the latter thermal/structural part of the problem would generally require a two- and possibly three-dimensional analysis. As it turns out, there are several quality tools of analysis (e.g., some of those reviewed in Ref. [1]), mainly for non-combustible construction, that are available for use in solving the latter problem. However, because of intense computational requirements, the general use of a multi-dimensional (vs. a one-dimensional) partition thermal analysis in the fire modeling part of the problem is not now practical. A basis is presented for identifying partition designs for which: (1) the use of one-dimensional thermal analysis in the fire modeling part of the problem would lead to reliable simulations of the fire environment, and (2) the resulting simulations can be used to provide the necessary boundary conditions input to solve the thermal/structural part of the problem, using two- or three-dimensional analyses, as required. Published by Elsevier Science Ltd.

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1. Compartment fire modeling, the room fire environment, and the thermal response of partitions

Two-layer zone-type compartment fire models are very useful in simulating analytically the various phenomena that occur during the course of compartment fire scenarios. Any particular model will typically predict some phenomena with relatively greater accuracy (i.e., with a relatively detailed/reliable set of governing equations), and will ignore and/or treat with limited detail/reliability other phenomena. As a consequence, the applicability, utility, and accuracy of any particular model will have corresponding strengths, weaknesses, and gaps.

The present work focuses on the aspect of modeling that encompasses the interrelationship between the thermal response of room partitions and room fire environments, leading to a capability of assessing thermal and structural partition fire resistance.

In discussing the room fire environment, emphasis is placed on reasonably accurate simulation of the temperature distributions or spatially averaged temperature distributions (vs, say, the distribution of gaseous products of combustion) throughout the volumes of the rooms of a simulated facility. Of all the features of the fire environment modeled by any particular compartment fire model, the prediction of the room temperature distributions typically receive the highest level of priority in modeling detail. This leads to a particular focus on the equations that describe the transport of energy and mass to/from the two layers of each room of the facility, i.e., heat and mass transfer exchanges at openings/vents and (especially heat transfer) at bounding surfaces, and the generation of heat and mass (e.g., from fire sources) within the layers of the rooms. In the usual way, and within the context of the two-layer zone-type description of the fire environment in a room, it is assumed that: (1) away from relatively small-volume regions that encompass and/or contact bounding surfaces, fire plumes, and positive or negative buoyant sources, the environment in each room of the facility can, at all times, be reasonably described as having uniform temperature upper and lower layers, (2) the upper and lower layers have relatively high and low temperatures, respectively, and (3) initially, the lower layer fills the room with ambient temperature air.

Particular emphasis is placed in the present discussion on the reasonably accurate simulation of the temperature distributions through the partitions, where the results of such simulations can be used to assess the integrity of the structures relative to their fire resistance. Here, the fire resistance of a partition would be an estimated time of possible thermal and/or structural failure, say, in the sense of failure as defined by the traditional evaluation methods of ASTM E119 [2] or ISO 834 [3].

To determine thermal and structural fire performance of partitions, it is necessary to solve thermal/structural problems via analyses of appropriate two- or three-dimensional models. The boundary conditions needed to properly formulate the latter problems would be obtained from the details of the fire environment to which the partitions are exposed. The latter would be obtained from a fire model simulation.

Because of energy conservation issues, the fire model has to also include a (sub)model for simulating partition thermal response. In this regard, what is generally needed is the simplest thermal model for the partitions that is consistent with a reasonably accurate fire model simulation of gas temperatures, and flows. For most, but not necessarily all of the exposed surfaces, this will generally require reasonably accurate simulations of partition surface temperatures, consistent with correspondingly accurate simulations of surface-to-surface and gas-to-surface heat transfer exchanges. All current zone fire models use one-dimensional (sub)models for partition thermal response.

If the latter "simplest thermal model" is simpler than the former two- or three-dimensional models, then there is a basis for uncoupling the problems of fire environment, on the one hand, and two- or three-dimensional thermal/structural performance on the other. If the latter "simplest thermal model" is a one-dimensional model, then the uncoupled problems can be solved with current technology. If the "simplest thermal model" is a two-dimensional model, then reliable solutions with current technology are not possible, whether or not the problems are coupled.

This work establishes conditions where the above "simplest thermal model" is a one-dimensional model, where the problems can be uncoupled, and where a reliable evaluation of thermal/structural performance in fires is tractable.

2. The dependence of accurate simulations of room fire environments on quality analyses of thermal response

Considerations of conservation of energy lead to the following "basic rule":

> *When the instantaneous surface-integrated rate of heat transfer to all partition surfaces of a facility is a significant fraction of instantaneous energy release of all contained fires, then an accurate estimate of the fire environment generally requires an accurate coupled analysis of partition thermal response (at least at the particular partition surfaces where the bulk of the heat transfer is taking place).*

The above rule is likely to be applicable when the simulated thermal response of the partitions will be used to evaluate fire-enhanced partition failure. It can also be applicable even when partitions are known to be nowhere near a state of failure, and when the details per se of the thermal response of the partitions are not of particular interest. The situation is exemplified by the set of full-scale, relatively-low-energy, nearly-fully-enclosed multi-room fire experiments of Ref. [4] (characteristic fire energy-release rates of the order of one hundred to a few hundred kW). There, while wall temperature data were not acquired at all, gas temperature measurements indicated integrated rates of heat transfer to all surfaces as high as 90% and greater of the fire's energy-release rate.

The above rules together with the experimental results [4] suggest that, in general, for a compartment fire model to yield accurate simulations of a room fire environment, an accurate analysis of partition thermal response is required.

When a fire scenario is such that the total integrated surface heat transfer rate is relatively small, then the above rule does not apply and an accurate partition heat transfer analysis is unnecessary. Indeed, in such cases even the simplest of all analyses, i.e., the analysis defined by the assumption of adiabatic surfaces, is adequate. It is noteworthy that the nearly-fully-enclosed aspect of the Ref. [4] tests is significant. Thus, in a well-ventilated single-room fire scenario, a contrasting type of scenario, the fraction of energy transfer to the bounding surfaces of the room is not expected to be nearly as significant. In the latter types of scenario the effects of heat transfer to partitions would play a much less significant role in affecting the room fire environment. Then, if partition performance is not a major issue, detailed analysis in a room fire model of the heat transfer through these bounding structures may not be necessary.

In most existing compartment fire models, the simulation of solid partition response is by way of locally one-dimensional (through the thickness) conduction heat transfer calculations. The idea is to "break up" the partitions of a modeled facility into a number of discrete partition segments or slabs, and simulate the thermal response of each. Typically, the material thermal properties of each segment are assumed to be spacially and temporally constant, e.g., simulation of temperature-dependent properties, or variations in material type through the thickness of a partition is not taken into account.

For many, real, solid partitions, use of the assumption of local one dimensionality of the partition heat transfer is likely to be reasonably accurate in the sense that, with small enough segments, a well-simulated accounting of conservation of energy throughout the facility, i.e., in the gas and in the solid barrriers, should usually be achievable. This is because in typical facilities the characteristic thicknesses of partitions are usually much smaller than their characteristic spans. As a result of this, through-thickness temperature gradients, and, therefore, heat transfer rates are typically much greater than temperature gradients and corresponding heat transfer rates in directions parallel to the partition surfaces.

Regarding variable material properties, there are situations where the use of spacially and temporally constant partition material properties can lead to reliable simulations of the fire environment. However, relative to common fire safety concerns, such situations would be restricted to typically uninteresting scenarios/times, where/when the temperature increases of partition surfaces are relatively small, e.g., possibly in the simulation of some or all of the experiments of Ref. [4].

When uses of a compartment fire model include evaluation of potential failure of partitions, model equations describing partition thermal response should include *temperature-dependent properties*. This is because, in practically realizable and threatening temperature ranges, the thermal properties of even the most common building materials vary significantly.

Finally, for a wider range of applicability, a model should ideally also include a capability of accounting for *variations in material type* through the thickness of a partition.

3. The validity and utility of a one-dimensional thermal response in cases where a two or three-dimensional analysis would be required to assess structural performance

Partition design in many practical facilities is such that, in the overall fire model equation set, use of locally one-dimensional analyses of their thermal response can lead to successful evaluation of their thermal fire performance. The idea is that, even though design features of common partition assemblies often exhibit regions where two- or possibly even three-dimensional thermal and structural effects are significant, in the sense of affecting significantly structural partition fire performance, these regions may be relatively sparse, and involve negligible heat transfer. Here the terminology "negligible heat transfer" is used in the sense that, for any particular partition of the facility, the integrated effects of heat transfer in the vicinity of these regions of multi-dimensional response are insignificant compared to the overall effects of energy conservation. Thus, (1) most of the through-partition heat transfer phenomena are well modeled by a one-dimensional analysis, and (2) the sparse regions of two- or three-dimensional partition behavior can be ignored in the room fire model analysis since use of a multi-dimensional analysis would only lead to minor modifications to calculated room fire environments.

In terms of the problem of carrying out practical compartment fire model analyses, the above observation is of very great significance. In particular, it essentially eliminates the need for computationally intensive compartment fire models, with model formulations that couple the conservation equations in the gas regions of a facility to two- or three-dimensional partition heat transfer analyses.

4. Example designs where the use of a one-dimensional partition thermal analysis would and would not be valid

To clarify the above ideas, it is instructive to identify partition systems where the use of one-dimensional partition thermal analyses would, and would not be valid.

4.1. *Gypsum-panel/steel-stud wall systems*

The first example is a class of gypsum-panel/steel-stud wall system design.

Fig. 1, adopted from Refs. [5,6], is a sketch of the wall system design. In general, two arbitrary-thickness gypsum wall panels are mounted one on either side of an array of vertical steel studs. In practice, each of the two panels shown can involve a single thickness of gypsum board or a sandwich-type multiple-thickness design of two or more well-contacted boards. Fig. 1 illustrates two particular assembly designs. One of these is referred to as a 1 × 1-type assembly, since each of the two panels involves a single layer of gypsum board. The other is a 1 × 2 assembly, since one panel is a single layer of gypsum board and the other involves a two-layer construction. The studs, spaced at regular intervals, form an unfilled air gap between the panels. Also, the studs are typically fabricated from relatively thin-gage steel (the studs used in the experimental study [5] were 0.46 mm thick) and they are not effective as paths for conductive heat transfer between the panels. As is the case in practical implementations of these kinds of wall systems, the spacing of the studs is several times the thickness of the air gap. Thus, in terms of earlier discussion on one- vs. two-dimensionality, it is only in relatively "sparse" regions of the wall system that the

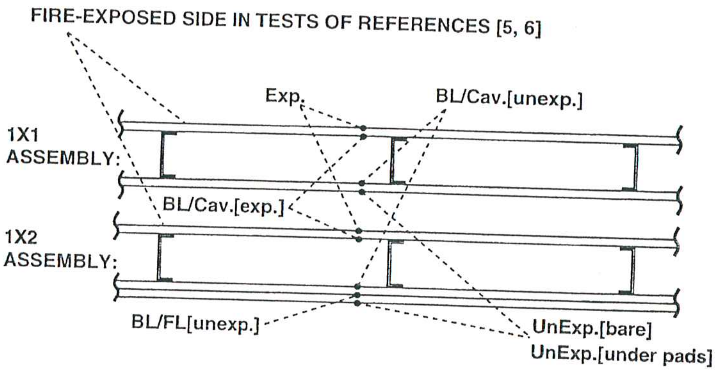

Fig. 1. Sketch of example gypsum-panel/steel-stud wall system designs (adopted from Refs. [2,3]); locations of calculated/measured temperatures in tests [2,3].

presence of the studs introduces two-dimensional considerations into the wall system geometry and heat transfer.

Extensive thermocouple data on the thermal response of a Fig. 1, 1 × 2-type wall system to ASTM E119 [2] standard-fire furnace exposures were acquired and presented in Ref. [5]. These data indicate that the temperature distribution in the gypsum panels, even relatively close to the steel studs, were substantially one-dimensional through the thickness of the panels. This finding and the experimentally validated one-dimensional thermal response models of Refs. [6,7] indicate that a compartment fire model whose model equations include a one-dimensional heat transfer analysis for gypsum-panel/steel-stud wall system thermal response can lead to an accurate overall accounting of energy conservation, and can yield accurate wall system thermal response simulations even up to a time of failure.

In spite of the above finding, heat transfer through gypsum-panel/steel-stud wall systems is not a totally one-dimensional phenomena. In particular, near the "sparse" regions of the stud/gypsum-panel joints, the heat transfer problem is strongly two-dimensional, i.e., an accurate determination of the steel-stud thermal response will require a two-dimensional time-dependent analysis (with two materials, steel and gypsum) of these regions. Furthermore, for load-bearing Fig. 1-type wall systems and in terms of the critical evaluation of wall system fire resistance, it is the spacially varying loss of strength of the steel studs due to spatially varying elevated temperatures that would lead to possible wall system structural failure, and that would have to be simulated. Nevertheless, for Fig. 1-type gypsum-panel/steel-stud wall systems, the use of a one-dimensional analysis in the overall fire model equation set can lead to accurate simulations of room fire environments and, away from the steel studs, an accurate simulation of wall system thermal response.

It is possible to implement the above ideas for the above class of gypsum-panel/steel-stud wall system by incorporating the modular wall model/algorithm, called *GYPST*, that was developed in Ref. [7], into a zone-type fire model such as *CFAST* [8]. The *GYPST* model assumes that: (1) relative to effects of conduction heat transfer,

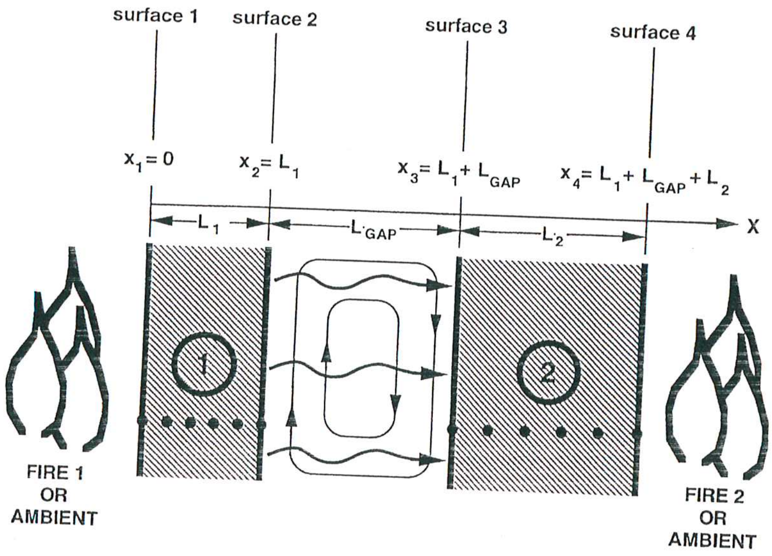

Fig. 2. Sketch of the idealized geometry of the gypsum-panel/steel-stud wall system.

the steel studs simply act as thermally insulating spacers for the gypsum panels, and (2) radiation exchanges across the air gap, between the facing surfaces of the gypsum panels, can be well-predicted by an analysis involving radiative exchange between two infinite parallel planes, i.e., the steel studs do not have a significant effect on modifying the radiation exchange between the facing panel surfaces. In the analysis, the time-dependent thermal responses of the gypsum panels are simulated by an idealized system involving two initially uniform-temperature vertical gypsum board panels, infinite in extent and separated by an air gap, where the system is always heated at the two bounding outer surfaces by spatially uniform heat fluxes. A sketch of the idealized wall system is presented in Fig. 2. The reader is referred to [7] for the details of the wall system heat transfer model and its associated computer subroutine, *GYPST*.

4.2. A reinforced concrete beam/slab system

The second partition example is that of a reinforced-concrete, beam/slab, floor/ceiling system. For the purpose of discussion, we choose a specific 2.44 m wide, 10 m long, double-tee module design from Problem 5.3 [9]. A section of this is shown in Fig. 3.

If the above ideas of one-dimensional analysis are applied to this beam/slab design, then implementation of energy conservation in the compartment fire model would involve an accounting of the thermal response of the overall beam/slab system via an analysis of heat transfer through a 0.102 m thick concrete slab (i.e., the combined lower 0.051 m-thick continuous cast slab and the 0.051 m-thick "topping"). However, such an analysis would not be consistant with the idea that regions of significant two-dimensional heat transfer are relatively sparse, involving only "negligible heat

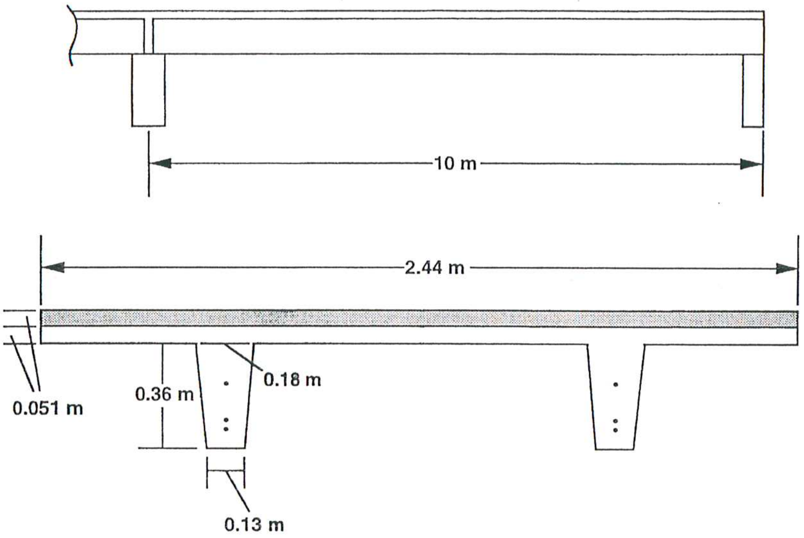

Fig. 3. Sketch of a section of a reinforced-concrete, beam/slab, floor/ceiling system (from Problem 5.3 [10]).

transfer". Indeed, in the design of Fig. 3, the region where two dimensionality is significant [i.e., through the two beam portions of the section, and through adjacent portions of the slab, say, up to half a beam depth (0.178 m) on either side of the beams] involves about 0.533 m of the width of the beam/slab module for each of the two beams of the module, i.e., 1.07 m or 44% of the total 2.44 m module width. This is not "sparse!" Furthermore, the beams are so deep (0.36 m) that they add a significant amount of exposed surface area to the lower-surface-to-gas heat transfer exchange, compared to the corresponding surface area that would be used in the one-dimensional analysis. In particular, compared to the one-dimensional lower surface area of (2.44 m width) × (10 m length) = 24.4 m^2 per module, the actual lower surface area involves an additional 4 × (0.36 m depth) × (10 m length) = 14.4 m^2, i.e., a 59% increase of surface area. Especially at the beginning of a fire scenario, such a large increase in surface area can be expected to lead to significant, rather than "negligible" additional amounts of heat transfer.

In view of the above, it is concluded that when dealing with Fig. 3-type beam/slab systems, the appropriate tool of analysis is a compartment fire model with an overall implementation of energy conservation that includes the effects of *two-dimensional heat transfer* (throughout the beam/slab). *It is noteworthy that no such compartment fire models currently exist.*

4.3. Other types of partitions

Additional examples of partitions where use of a one-dimensional thermal analysis in the room fire model part of the problem *would likely lead to reliable results* are:

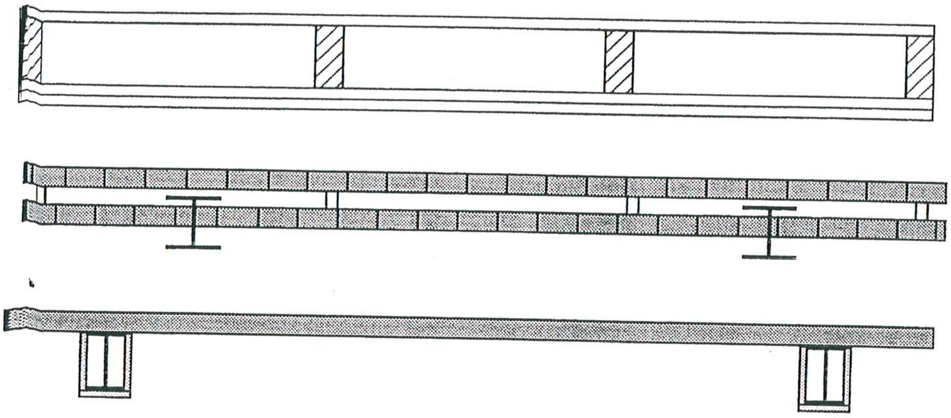

Fig. 4. Sketch of examples of partition design where use of a one-dimensional thermal analysis may lead to reliable results.

- Fig. 1 – type gypsum-panel wall system with wood instead of steel studs, but prior to times of significant energy release from charring/burning studs.
- Concrete block wall with built-in sparsely spaced steel columns.
- Poured concrete slab supported on steel beams, where, in difference to the Fig. 3 - type reinforced-concrete beam/slab system, regions of significant two-dimensional beam/slab heat transfer are relatively sparse and involve "negligible" heat transfer.

These are shown in Fig. 4.

Other examples where use of a one-dimensional thermal analysis *may not lead to reliable results* are:

- Composite concrete slabs with profiled steel sheets (metal deck floors).
- Uniform-thickness concrete slabs with regularly spaced inclusions.

These are shown in Fig. 5.

5. A basis for using simulated fire environments, involving a one-dimensional analysis of thermal response, to determine two- or three-dimensional structural response

In the present work, attention is focused on fire scenarios where regions of multi-dimensional partition heat transfer are relatively sparse, etc., i.e., fire scenarios where use of a one-dimensional thermal analysis in compartment fire model energy conservation equations is consistant with reliable simulation of the compartment fire environment. For a particular problem of interest, the output from such a simulation would be used to provide the partition heat flux boundary conditions necessary to solve the now-multi-dimensional thermal/structural part of the problem. The latter

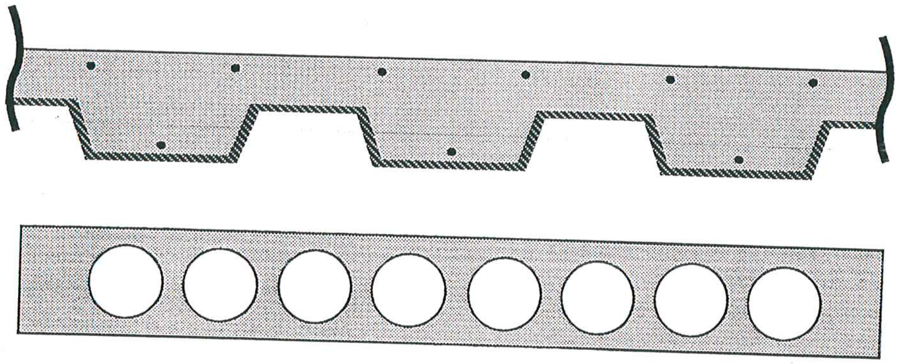

Fig. 5. Sketch of examples of partition design where use of a one-dimensional thermal analysis may not lead to reliable results.

problem would be formulated and solved with the use of an appropriate computational/computer tool of analysis, several of which are currently available (see, e.g., [1,10,11]).

Two kinds of fire model output can be used to specify heat flux boundary conditions for multi-dimensional simulations of thermal/structural response. The first kind of output is obtained from models that allow simulated gas layers to be of arbitrary transparency. For such models, the time-dependent rates of incident radiant heat transfer to each of the fire-model-defined partition surface elements (assumed uniform across the surface of any particular surface element, but generally varying from element-to-element) will have been computed during the fire model simulation. These can be used directly to construct time-dependent net radiant fluxes for the thermal/structural analysis. Also, the calculated adjacent layer gas temperatures and/or, where appropriate, the temperatures and velocities of near-surface boundary flows would be available to construct time-dependent convective heat transfer fluxes.

The second kind of fire model output for specifying heat flux boundary condition to a particular surface element is simply the calculated, adjacent-layer, gas temperature. Existing thermal/structural fire response models typically carry out their multi-dimension thermal analyses with simplified combined radiation and convection surface heat flux boundary conditions calculated from such gas temperature specificatons. The formulation typically follows that prescribed in Ref. [12], viz,

$$\dot{q}''_{S,M} = \varepsilon_{EFF}\sigma(T^4_{G,M} - T^4_{S,M}) + h(T_{G,M} - T_{S,M}), \tag{1}$$

where, $\dot{q}''_{S,M}$ is the net heat flux to surface element M, at temperature $T_{S,M}$, $T_{G,M}$ is the temperature of the gas layer in contact with the element, σ is the Stefan Boltzman constant, ε_{EFF} is a resultant emmisivity, and h is an effective convective heat transfer coefficient.

For real room fire scenarios, the first of the above types of specification is more general than the second. However, it would typically be difficult to apply in practice. The second specification is relatively simple to apply, but it cannot be relyed on for accuracy except when adjacent gas layers are nearly opaque.

To appreciate the difficulty of applying the general formulation, consider the fact that, even when regions of multi-dimensional heat transfer are "sparse" and "negligible", the rates of heat flux to and the distribution across the relatively small exposed surfaces of such regions can vary significantly from the previously predicted spacially uniform heat flux. For example, in a fire scenario with relatively transparent gas layers, shading of potentially intense radiation from a fire combustion zone to a partition surface could occur as a result of local surface protrusions, e.g., in the neighborhood of the "sparsely" distributed beams of the beam-supporting floor/ceiling slabs of Fig. 4. What is important here, is that such shading could lead to significant variations in rates of heat transfer across these sparse, but now-critical-region surfaces (e.g., the exposed surfaces of the above-referenced "sparsely" distributed beams whose structural integrity is being investigated). Such variations could have a significant effect locally on the multi-dimensional in-depth temperature distribution and, ultimately, on the structural response of the partition.

In the forseeable future it is not reasonable, and it may never even be practical, to expect an analytic capability that can take general account of the above spacially variable local flux distributions. This situation leads to a dilemma relative to formulating accurate thermal/heat transfer boundary condition for the thermal/structural part of the problem.

Note that the difficulty in a general analysis of the radiation exchange problem, and the resulting dilemma, comes about as a result of the assumption of a relatively transparent, vs, say, a nearly opaque contacting gas layer. Thus, if the gas layer in contact with the partion surface is nearly opaque, the effect of through-gas radiant transfer is negligible, and essentially all radiant transfer to surfaces, including the radiation to surfaces local to "sparse" protrusions, is a result of direct gas-layer-to-surface radiation exchange. Whereas the general determination of radiant heat transfer exchanges in the case of relatively transparent contacting layers is problematic, when the contacting gas layers are nearly opaque the problem becomes much more manageable. Indeed, it would appear that the nearly opaque adjacent-gas-layer formulation is a basis for use of the commonly used Eq. (1)-type heat flux specification.

A practical means of resolving the above dilemma is achieved by adopting the following, reasonable, heuristic assumptions:

1. The more opaque the upper gas layer, the greater the rate of heat transfer to upper-layer-submerged surfaces, i.e., the net radiant heating to such surfaces that would be estimated in the case of an opaque upper layer is assumed to exceed the actual net radiant heating. The latter would include incident radiation from the combustion zone and from often-relatively-low-temperature facing surface elements and through the gas layer(s), and incident radiation from the gas layers themselves.
2. The more intense the heating of particular partition/boundary surface elements, the smaller the fire resistance of the overall partition structure.
3. The upper layer gases are near opaque.
4. The rate of heat transfer to the partition surfaces in contact with the lower layer gases are adequately estimated by the fire-model-simulated spacially uniform

fluxes to the "one-dimensional" portions of those segments. Note that in the most threatened room of a modeled burning facility, in the room of fire origin, the fraction of lower-layer-exposed wall surfaces would often be relatively small, since the elevated-temperature upper layer gases would typically fill most of the space, i.e., they would submerge the ceiling surfaces and most of the wall surfaces. Regarding the floor surface, it would typically not include the above-mentioned two-dimensional-type protusions. Therefore, incident heat transfer to floor surfaces elements would be well-simulated by the estimates available from the fire model simulation.

The first three of the above assumptions allows for a relatively simple, straightforward, and presumedly conservative estimate (relative to calculations of fire resistance based on partition thermal and structural response) of the rate of heat transfer to all upper-layer-submerged surfaces. This would be based on the simulated time-dependent temperature of the upper layer and the use of Eq. (1).

An even-simpler, but more conservative alternative to assumption 4 is

4a. The rate of heat transfer to the modeled segments of those remaining portions partition surfaces, in contact with the lower layer gases, are also conservatively estimated by Eq. (1). In particular, it is assumed that they are heated at the same rate as if they were in contact with and directly exposed to an opaque gas layer with upper layer gas temperature.

6. Determining the two- or three-dimensional structural response of partitions to compartment fire environments

With the above assumptions 1–3 and 4a, simulation results of an adopted compartment fire model would yield, via Eq. (1), rates of heat transfer to *all* surfaces of all rooms of a modeled facility, even to surfaces of sparse regions where in-depth multi-dimensional heat transfer is prevalent. These surface fluxes would be used to specify boundary conditions for the initial/boundary value problem(s) describing the multi-dimensional thermal response of the facility partitions.

The latter boundary value problems are of the type that can be solved by a class of computational models designed to determine the thermal and structural response of structural elements exposed to fire or to other elevated-temperature environments (see, e.g., [1,10,11]). With the availability for input of the now-known surface heat fluxes, these computer models would typically be used to first solve for the temperature field thoughout a structure of interest. In problems of present concern, these would be partition structural elements. The computed temperature field would then be used, together with appropriate boundary conditions, to solve for the desired structural response.

The thermal/structural fire model, *SAFIR* [13], developed and currently being advanced at the University of Liege, has been identified and used as a reliable thermal/structural computational model for exploring and implementing the latter idea. Preliminary applications of *SAFIR* at the Center for Advanced Technology for Large Structural Systems (ATLSS) of Lehigh University [14]and at the University of Maryland [15] indicate that the above approach to coupling a compartment fire model and a thermal/structural fire model will be successful.

7. Summary and conclusions

Design features of common partition assemblies often exhibit regions where two- or possibly even three-dimensional thermal and/or structural effects are important, in the sense of affecting significantly structural partition fire performance. However, for some such assemblies, these regions may be relatively sparse, and, compared to characteristic energy transfers in room fires, involve negligible heat transfer. Also, away from the these regions and for most of the partition structure, it is often the case that the thermal response of the partition can be modeled reliably as one-dimensional through its depth. Under such circumstances, the partitions can be classified as "quasi-one-dimensional" in the sense that a one-dimensional thermal analysis of partition response in the room fire model would provide the appropriate level of modeling detail in room fire environment simulations. Then, the problem of determining the room fire environment via a room fire model can be uncoupled from an appropriately detailed two- or three-dimensional problem of thermal and structural response, where the solution to the former would provide the thermal boundary conditions for the latter.

The above ideas, developed at length in this paper, result in the following recommended steps/considerations for a reliable determination of the thermal/structural response of partitions to room fire exposures, where, in the above sense, the partitions are "quasi-one-dimensional":

(1) The analysis of thermal/structural response will require a fire model simulation of the exposure room fire environment. In terms of current technology, this will depend on the appropriate reliability of a one-dimensional model of partition thermal response. Such reliability would have to be established from the considerations discussed earlier.

(2) A fire-model simulation with assumed opaque upper layers should be used to estimate upper/lower layer temperatures. In the simulation, the thermal response of the partitions may or may not have a significant effect on the results.

(3) The initial/boundary value problem for the two- or three-dimensional thermal response of the partition should be formulated and solved. Thermal boundary conditions at exposed surfaces are obtained by using upper layer solution temperatures, obtained in the item 2 simulation, to specify time-dependent heat transfer rates via Eq. (1).

(4) With appropriate constraints, the partition solution temperature field from item 3 should be used with an appropriate two- or three-dimensional structural model, to solve for the structural response of the partition.

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