COMMENTS ON "CORRECTION FACTORS FOR THE HEAT OF COMBUSTION IN NFPA 72 APPENDIX B"

by William Davis, Ph.D.

I want to express some reservations concerning the revision to NFPA 72 Appendix B[1] that is being considered based on an article by Christopher E. Marrion in *Fire Protection Engineering*[2]. The rationale for this revision is based on a paper published by Heskestad and Delichatsios[3] in which the correlation[4] (H&D) used in NFPA 72 Appendix B was modified due to an updated measurement for the heat of combustion of sugar pine. The revision is substantial in that the heat of combustion for sugar pine is reduced by a factor of 1.67 which significantly changes the relationship between convective heat release rate and excess temperature at the ceiling. Changes such as theses, which substantially impact the way fire protection engineers perform detector placement analysis, should be verified using independent supporting experiments in order to avoid dependence on a single investigation. Heskestad and Delichatsios were very careful in their original paper to compare their measurements with existing experimental data in order to verify that the results were supported with comparable experiments. In their revision, when the heat of combustion was changed, no comparison was made to the results of other experiments.

Since the H&D correlation was based on a t-squared fire, the time dependent portion is difficult to verify using existing experiments. One can look at the quasisteady form of the H&D correlation as Heskestad and Delichatsios did in their first paper. In that paper, favorable comparisons of plume and ceiling jet temperature excess were made with alcohol pan fires. Later, Evans[5] compared the quasisteady form of this algorithm with Alpert's ceiling jet correlation[6] and found that the H&D correlation predicted somewhat higher temperatures and velocities. With the corrected release rate, both of these comparisons will yield poorer results as the excess temperature at the ceiling will be about 40% higher for an equivalent heat release rate.

The original H&D (quasisteady form) gives the excess temperature at the ceiling to be:

$$\Delta T = \left[\frac{T_\infty}{c_p^{\,2}\rho^{2} g}\right]^{1/3} \frac{\dot{Q}^{2/3}}{H^{5/3}}\left[0.188 + 0.313\frac{r}{H}\right]^{-4/3}$$

where for a temperature of 20°C, the first bracket has a value of 9.285. Evaluating this expression at r=0.0m (plume centerline) yields

$$\Delta T = 25.5\frac{\dot{Q}^{2/3}}{H^{5/3}}$$

If the heat release rate is corrected for the revised heat of combustion of wood, the plume centerline temperature equation becomes

$$\Delta T = 36.0\frac{\dot{Q}^{2/3}}{H^{5/3}}$$

Beyler[7] has suggested that 22.0 should be used with the total heat release rate, while 26.0 should be used with the convective heat release rate. This observation was based on a number of experiments which included nonradiative heat sources as well as different fuel sources. The revised coefficient of the H&D correlation is substantially larger than these values while the original coefficient is close to the suggested values.

It is also instructive to look at the measured radiative frac-

Reference	Ceiling Height	Fuel Source	HRR	Excess Layer Temperature	Draft Curtain Depth
Evans[9]	0.58 m	Methane	0.62 kW	30 °C	0.29m
Hinkley[10]	10 m	Hexane	4.6 MW	85 °C	3.2m
Gott[11]	15 m	JP-5	Various	Various	3.7m
Gott[11]	22 m	JP-5 & JP-8	Various	Various	8.9 m

TABLE 1. EXPERIMENTS WITH UPPER LAYERS

SYMBOLS

c_p	heat capacity of air at constant pressure
g	acceleration of gravity
H	height of ceiling above the fire surface
$\dot{Q}$	heat release rate
$\dot{Q}_c$	convective heat release rate
r	radial distance from plume centerline
T_a	ambient temperature
ΔT	excess temperature
ρ	density of air

tion for these experiments. Heskestad reported a value of approximately 0.25 for wood pallets based on measurement and this value is used to derive the constant for the convective heat release rate correlation. This value for radiative fraction is slightly lower than the 0.3 value for wood published by Tewarson[8]. Using the 0.25 radiative fraction, equation 3 becomes

$$\Delta T = 43.5\frac{\dot{Q}_c^{2/3}}{H^{5/3}}$$

In order to gain additional insight into the accuracy of the revised version of the H&D correlation, it is useful to compare its predictions with experiments where a substantial hot upper layer has developed. One would expect that the H&D correlation would underpredict the plume centerline temperature for these experiments since it is based on a set of measurements where a smoke layer did not develop and hence the plume would not include entrained hot upper layer gas.

Figures 1, 2, and 3 display the comparisons using equation 4 (revised H&D correlation) and the plume centerline temperature measurements close to the ceiling for the experiments tabulated in Table 1. The calculations are performed after steady state burning has occurred and a stable upper layer has developed. The uncertainty intervals for the calculations represent uncertainties in the input value. The revised H&D correlation consistently predicts or overpredicts the plume centerline temperature for all experiments. These comparisons contradict what would be expected of the revised correlation. The revised correlation should underpredict the plume centerline temperature for these experiments as the correlation is based

Figure 1. Comparison of Measured and Predicted Excess Temperature for 0.58 m and 10 m Ceiling Heights

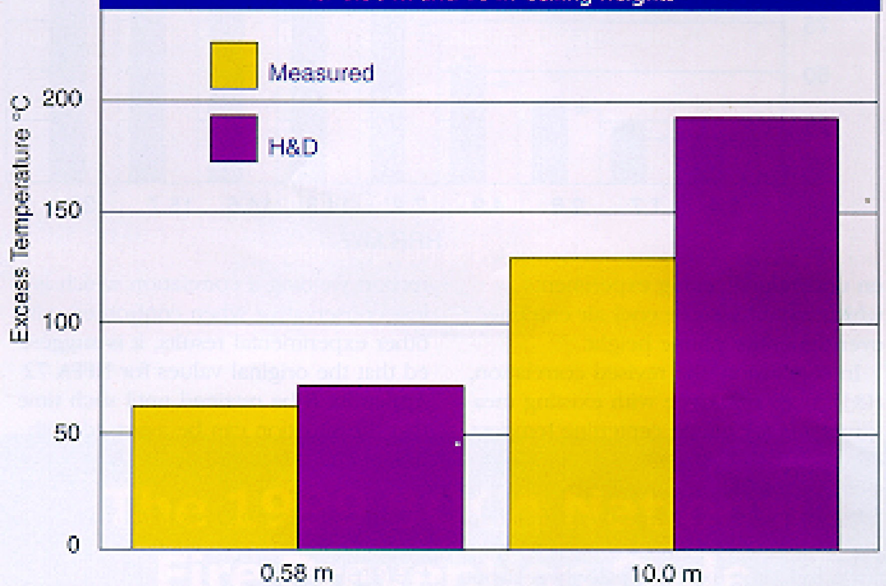
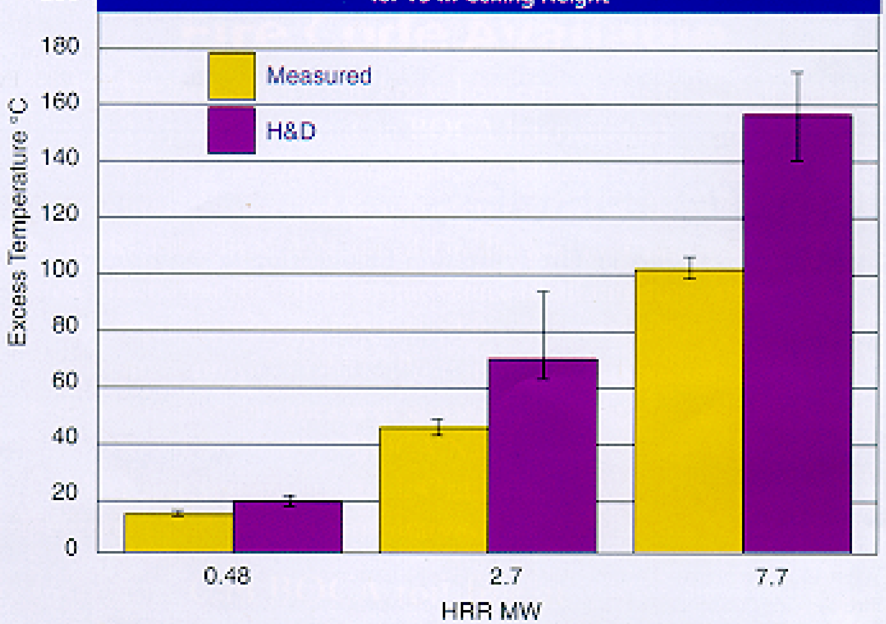
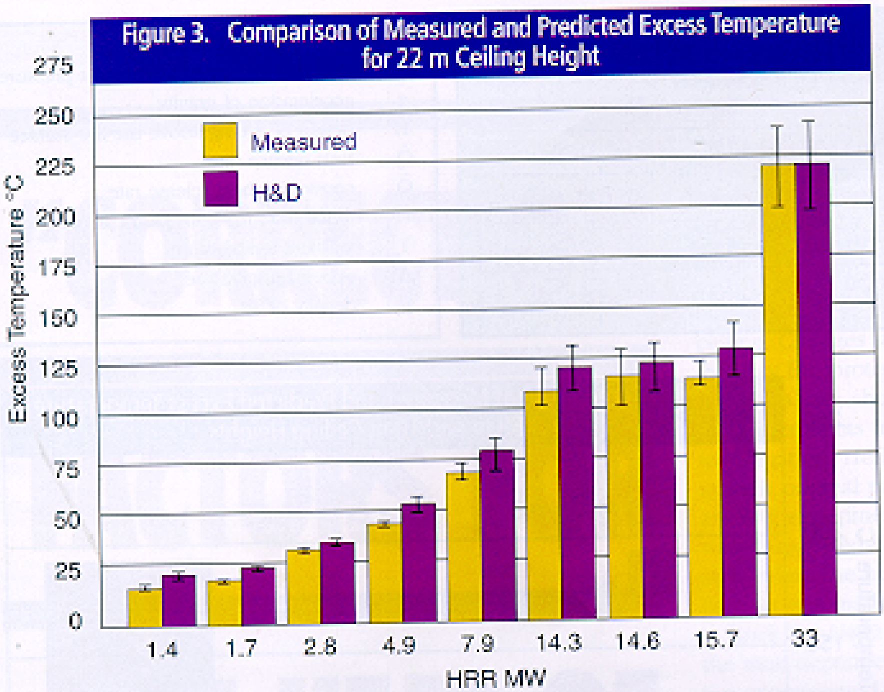


Figure 2. Comparison of Measured and Predicted Excess Temperature for 15 m Ceiling Height





on unconfined ceiling experiments which would assume cool air entrained over the entire plume height.

In conclusion, the revised correlation, H&D, does not agree with existing measurements for plume centerline temperature in unconfined ceiling situations using either nonradiative heat sources or other fuel sources. While the correlation did predict the plume centerline temperature for some experiments where a hot upper layer developed, it should have underpredicted these temperatures as it was derived from unconfined ceiling situations. With the uncertainty surrounding the measurements reported in this experiment and with the suggested correction yielding a correlation which is less conservative when confronted with other experimental results, it is suggested that the original values for NFPA 72 Appendix B be retained until such time that the situation can be assessed with independent measurements. ▲

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