

AN ANALYSIS OF THE PERFORMANCE OF RESIDENTIAL SMOKE DETECTION TECHNOLOGIES UTILIZING THE CONCEPT OF RELATIVE TIME

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ABSTRACT

Since the inclusion of smoke detectors in residential fire safety plans, several experimental studies have been undertaken to evaluate the effectiveness of the most common types of residential smoke detectors: ionization, photoelectric, and combination. The most notable studies are the NIST Indiana Dunes tests from the 1970s [1], and the more recent 2003 NRC Canadian Kemano [3] and NIST Dunes 2000 studies [4]. A common problem when evaluating smoke detector technology performance from these and other studies is that the fires and smoke sources can vary from test to test. Likewise, detector locations, test geometries, and fire locations often vary from study to study. Due to these variations in fire growth and smoke concentration and velocity at different detector locations, smoke detector activation times have been comparable only for detectors used in the same test and sited at the same location. Comparisons across a broader range of experiments and locations have been difficult at best.

This study introduces a new concept for the evaluation of the effectiveness of smoke detector technologies. This new analytical technique utilizes a non-dimensional relative time, where the activation time of a smoke detector in a specific test is normalized based on the activation time of the first detector to alarm at that location in that particular test. Utilizing this technique permits the researcher to account for different fire development times among the various flaming and smoldering fire studies. By normalizing the activation times in this manner, the test-specific variables no longer influence the comparison, and results from several tests can be compared simultaneously to determine overall trends. This normalization leaves only the type and sensitivity of each smoke detector as the relevant variables. The results of the Dunes (1970s), 2003 Kemano, and Dunes 2000 tests have been analyzed using this new relative time methodology. In total, 2,843 data points were analyzed in this manner.

These three fire studies were first evaluated individually. For each test, photoelectric, ionization, and combination detectors were assigned to a group based on their placement in the building. For example, all of the detectors on the ceiling of a certain room were considered one group. Typically, each cluster contained a variety of detector types, although there were occasional exceptions. The first detector in each group to react to the test fire was noted, and each individual detector's relative time to activate was then found by dividing its absolute sounding time by the absolute time of the first detector to sound in that particular group:

$$t_{act,rel} = \frac{t_{act,abs}}{t_{act,abs,first}}$$

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Utilizing this methodology, the detector in each group that first activated will have a relative time of one, while the group's other detectors will have relative times exceeding one. By looking at the relative time of each detector instead of the absolute time, results from several studies and tests can be compared while eliminating differences such as fire growth rate or detector location. Thus, instead of examining the performance of any one detector, the relative performance of a detector compared to other detectors under the same conditions is examined. For example, the relative times from a specific smoldering test from the Kemano study are shown below as Figure 1.

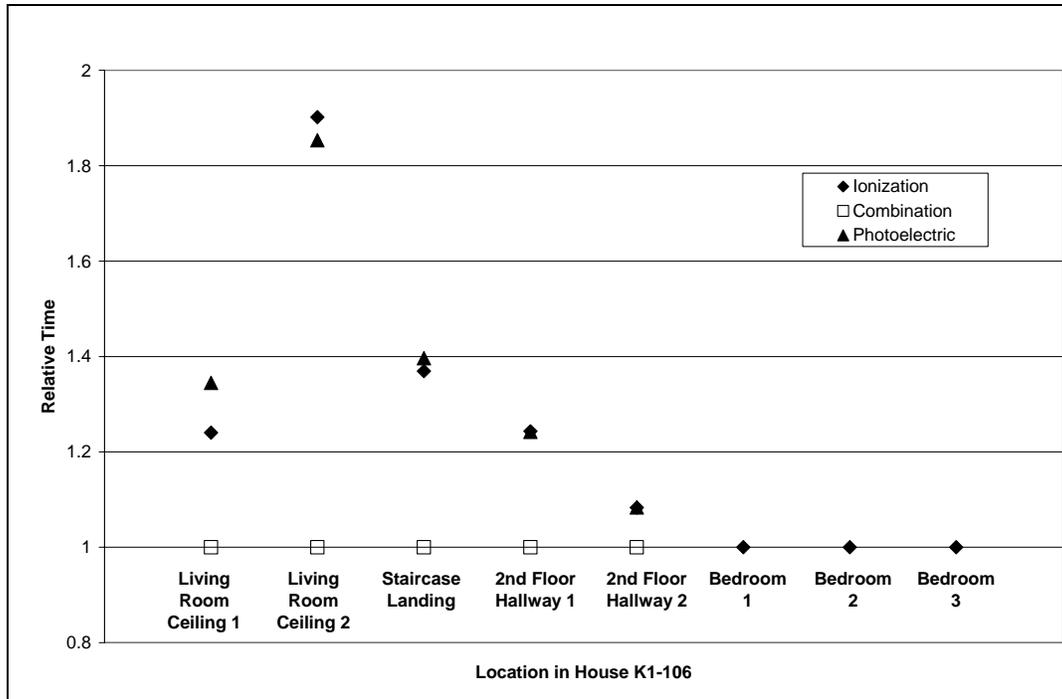


Figure 1. Relative time results for a smoldering fire that transitioned to flaming (Kemano [3] Test 12).

After each test from these three studies was analyzed in this fashion, the results were consolidated into 3 categories based on fire type: smoldering, flaming, and kitchen. The average relative time to detector activation for each type of detection technology was calculated, and a 95% confidence interval (i.e., two standard deviations) was determined and plotted. Data that were not within three standard deviations of the average were omitted, since these results were often found to be caused by data acquisition errors. These errors were confirmed from test data of the monitored voltage of the detector or from test notes from the experimental team, thereby justifying the omission of the data outside three standard deviations. Likewise, activation times from any detectors that activated in a manner very inconsistent with other detectors at a given location or in an obviously erroneous way were not considered, because this data skewed the results. These errors occurred most often in the Dunes 2000 tests, where the monitored voltages showed considerable noise. In many cases, this electrical noise inferred detector activation, based on the NIST protocol, even though smoke had not yet arrived at the detector location. The plots of the data for the three types of fires, smoldering, flaming, and kitchen, are shown below as Figures 2-4.

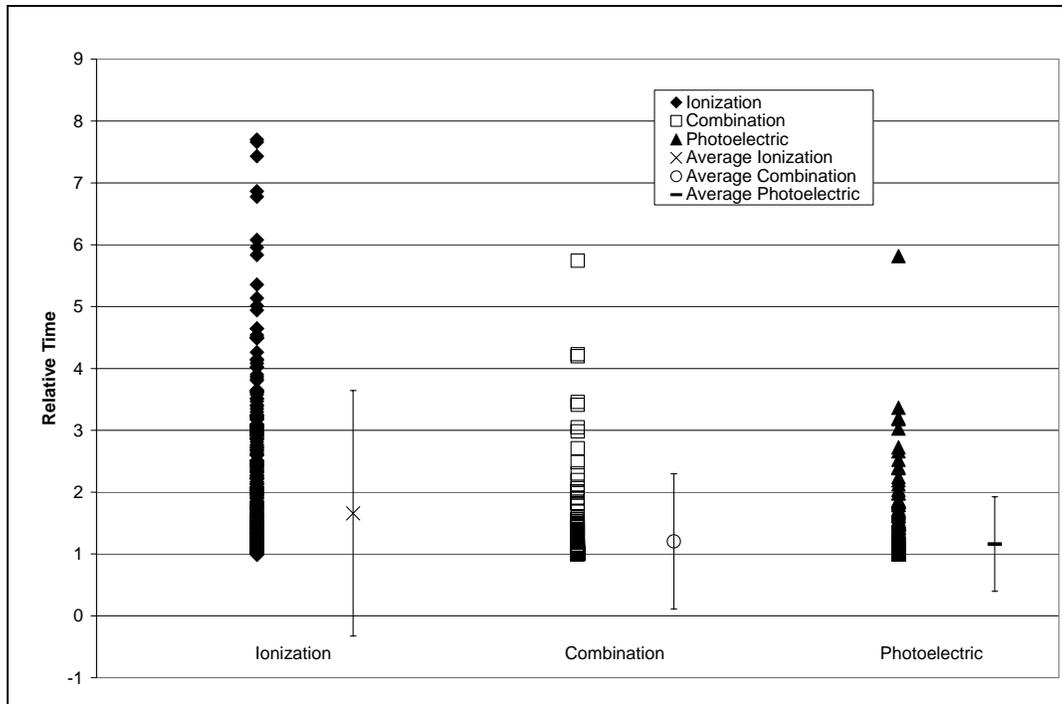


Figure 2. Relative time data for all of the smoldering tests from the Dunes [1], Kemano [3], and Dunes 2000 [4] studies. The average value and the 95% confidence interval for the different detection technologies are also shown. .

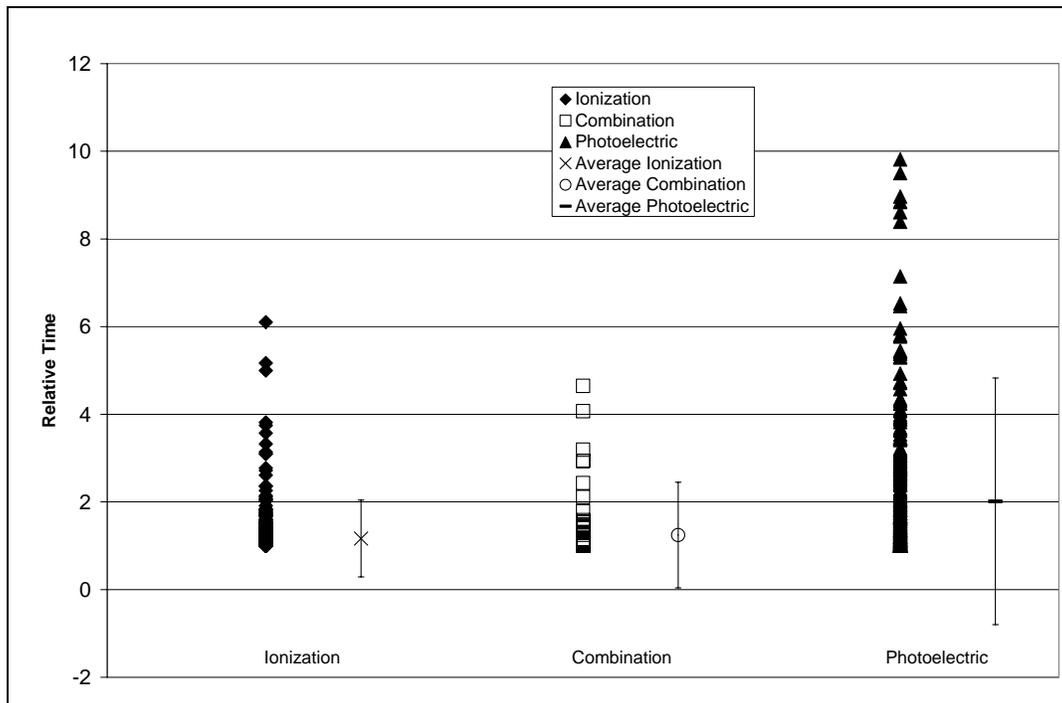


Figure 3. Relative time data for tests using the flaming fires from the Dunes [1,2], Kemano [3], and Dunes 2000 [4] studies. The average value and the 95% confidence interval for the different detection technologies are also shown.

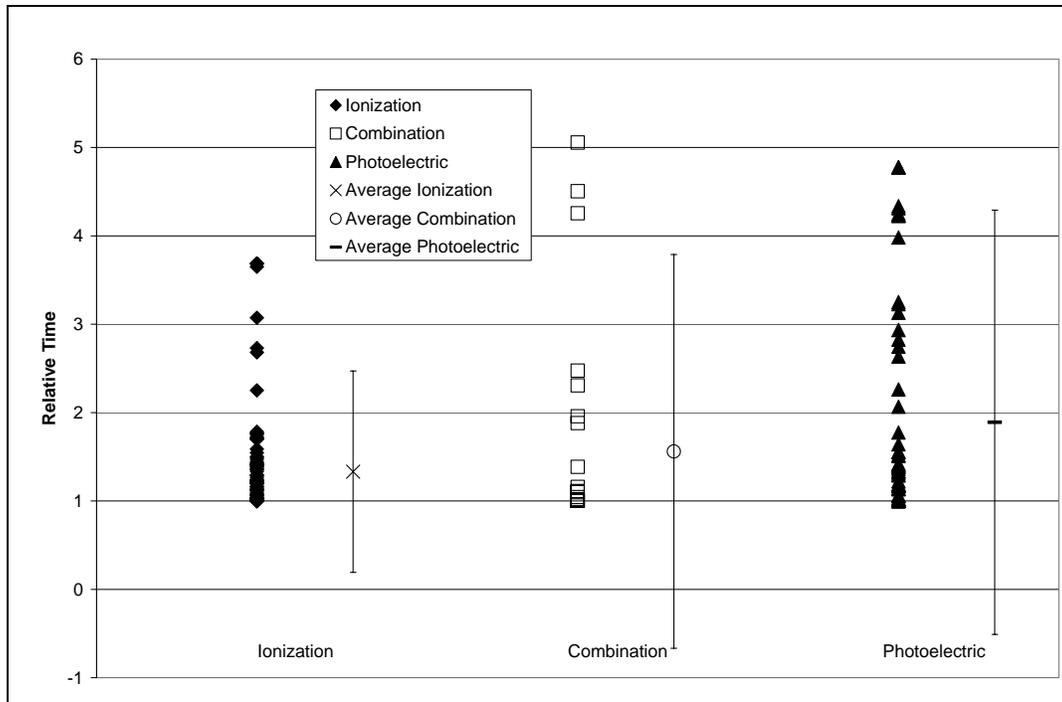


Figure 4. Relative time data for kitchen fire tests from the Dunes [1 2], Kemano [3], and Dunes 2000 [4] studies. The average value and the 95% confidence interval for the different detection technologies are also shown.

As can be seen from the figures above, this study found that ionization smoke detectors are generally faster at responding to flaming fires, and photoelectric smoke detectors are generally faster at responding to smoldering fires. This conclusion, based on the average of the relative times for both types of detectors and both kinds of fires, is in agreement with the conclusions of previous studies. Ionization detectors were also faster at detecting kitchen fires. While this generality that ionization detectors are faster at detecting flaming fires and that photoelectric detectors are faster at detecting smoldering fires was confirmed, this study determined that overall there is no statistically significant difference between the activation time of ionization and photoelectric detectors when the entire data set is considered.

This conclusion that there is no statistically significant difference in the activation times of ionization and photoelectric detectors is based on the small difference in their average response times when compared with the considerable overlap of the confidence intervals of the data. This finding demonstrates that while one detection technology may on average be slightly better than another for a particular type of fire, there is no statistically significant difference between the detection technologies. Hence, for a fire of any given type, there is no statistical guarantee of which type of detector will detect that fire first. Therefore, this analysis shows that ionization, photoelectric, and combination technologies are essentially equivalent for the detection of household fires.

This finding is not surprising, because identical testing requirements are placed on all smoke detection technologies. All detectors, regardless of what detection technology is used, must pass UL 217 [5] or UL 268 [6], and thus should have similar detection capabilities across all fire types. Figure 5, presented below, shows the relative time performance of the three detector types to all types of fires for both the Dunes testing in the 1970s and the more recent Dunes 2000 testing. Note that the average activation times for the different technologies are

quite similar for both data sets. This figure indicates that the relative performance of ionization and photoelectric technologies has not changed significantly over the past 35 years, since there was not and still is not any statistically significant difference in the performance of ionization, photoelectric, or combination detectors. Therefore, the conclusions of the original Dunes testing of the 1970s that either ionization or photoelectric detectors provide adequate warning for most household fires still have application today. These conclusions endure even though fuel types have changed and absolute activation times and provided escape times may have been reduced.

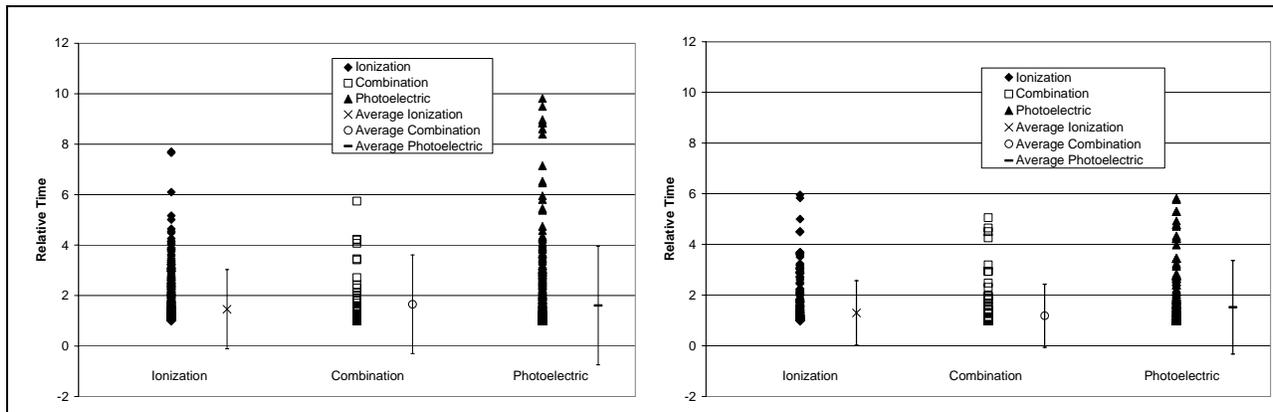


Figure 5. Relative time data for all the fire tests for the Dunes tests (1970s) (left) [1,2] and the Dunes 2000 tests (right) [4]. The average value and the 95% confidence interval for the different detection technologies are also shown.

Furthermore, this study found that ionization detectors showed greater scatter in detection time of smoldering fires, and photoelectric detectors showed greater scatter in detection time of flaming fires. This result can be seen in the variability of the data and in the magnitude of the confidence intervals in Figures 2 and 3 above. In addition, combination detectors were found to offer no statistically significant better performance than an ionization or a photoelectric detector singularly, regardless of fire type. Combination detectors, though, showed less scatter in detection time than either ionization or photoelectric detectors. Despite this minimal advantage, combination detectors inevitably will have more false alarms, since they will alarm to nuisance sources for both ionization and photoelectric detectors. This potentially negative aspect of combination detectors was not explicitly considered in this study.

Finally, the data from all of the fire types was combined into one comprehensive graph, which is shown below as Figure 6. When the data for each given detector type is averaged, it becomes apparent that all the detection types are statistically equivalent at a 95% confidence level. In practice, this means that if the next fire type is unknown, as will generally be the case, ionization and photoelectric detectors are, on average, equivalent for detecting the fire. Moreover, even if the next fire is known, consumers can be confident that they will be getting equivalent performance compared with other detection technologies regardless of what type of detector is installed. Combination detectors performed slightly better on average than either the ionization or the photoelectric detectors, but again, unless the detection chamber signals are combined with computer algorithms (e.g., the response of one chamber is used to confirm the response of the other), which would change the relative time results, the combination detector will be more prone to false alarms.

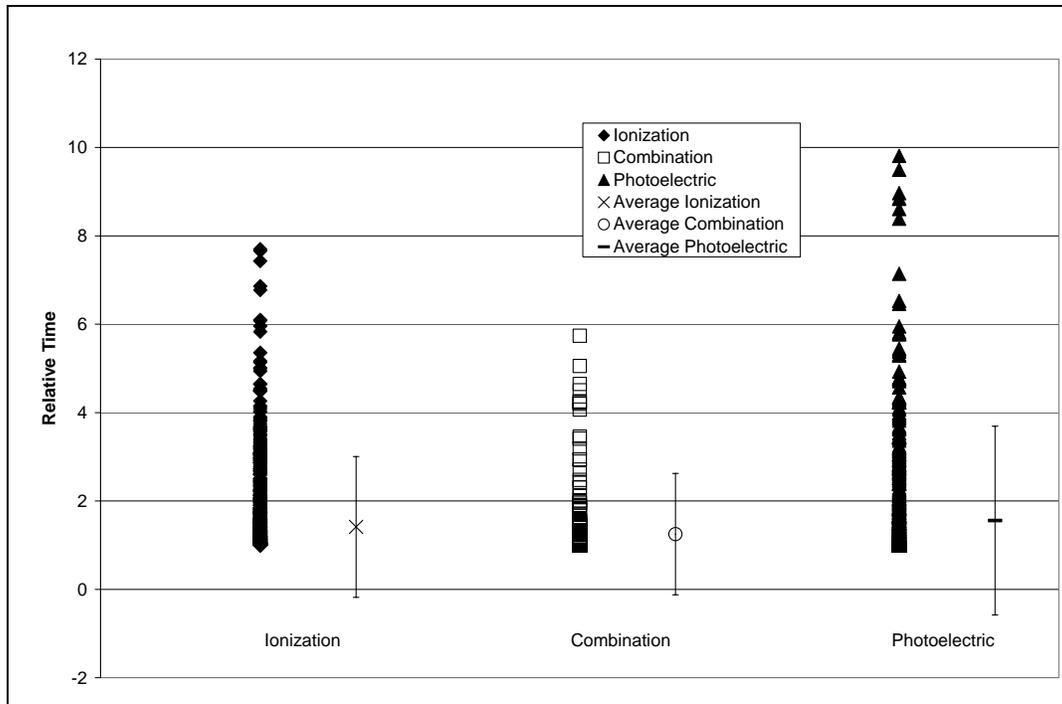


Figure 6. Relative time data for all tests from Dunes [1], Kemano [3], and Dunes 2000 [4]. The average relative time for each detection technology is also shown, along with the 95% confidence levels. The total number of data points analyzed was 2843.

In summary, this study demonstrates that ionization, photoelectric, and combination detectors provide statistically equivalent warning to different types of fires. This finding holds for the Dunes studies in the 1970s, and still holds today for the 2003 Kemano and Dunes 2000 studies, showing there has been no noticeable increase in the effectiveness of one type of detector over another in the last 35 years. This conclusion is still valid even as different furnishings have been introduced into the market and as other changes in residential fire hazards have occurred over this time period. The results from this study clearly show that instead of continuing to debate which technology is currently better, installation efforts should emphasize maximizing the number of detectors in residences. Similarly, research efforts should be focused on lowering the absolute time for activation of all detectors while decreasing false alarms through nuisance source rejection. By focusing on reducing time to activation and on reducing false alarms, relative time will effectively remain unchanged, but overall fire safety for occupants of a residence will be increased.

ACKNOWLEDGEMENTS

This work was sponsored by Internal Research and Development funding from Combustion Science & Engineering, Inc. The authors wish to thank Dr. Jose Torero of the University of Edinburgh for his informative discussions on the topic, as well as Dr. Michael Klassen of Combustion Science & Engineering, Inc. for his aid in formulating the statistical analysis.

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