# Biomass Smoke Exposure in Wildland Firefighters During Prescribed Burn Events


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## ABSTRACT


As a result of their proximity to fire fronts and lack of respiratory protection, wildland firefighters are exposed to high levels of biomass smoke containing fine particulate matter ($PM_{2.5}$)[1] while undergoing physically demanding tasks. Exposure to biomass smoke is considered the greatest risk factor for disease development among firefighters[2], however the comprehensive health impacts of occupational exposures to biomass smoke is still not well understood.

Wildland firefighting is a physically demanding occupation where firefighters cover large amounts of difficult and remote terrain carrying heavy packs and performing manual labor under extreme environmental conditions (high winds, steep terrain, elevated temperatures). Exposure assessments under these conditions are challenging and limited due to the hazardous and remote nature of wildfires.

In this study, we monitored personal exposures to smoke aerosol of prescribed burn (Rx) firefighters under real occupational conditions without interfering with their assigned tasks or safety. The firefighters wore continuous monitors to quantify $PM_{2.5}$ spatial patterns.

$PM_{2.5}$ spatial patterns were highly variable reflecting differences in assigned task, physical activities, and location to the fire front throughout the events. Higher $PM_{2.5}$ concentrations were observed during elevated activity parameters and lower elevations, suggesting potential for elevated internal dose as a result of working task. Elevated activity during high periods of $PM_{2.5}$ may lead to higher constituents reaching target organs and elevated systemic distribution; warranting the need for further investigation.


## SITUATION/PROBLEM

Respiratory protection is rarely utilized by firefighters during wildfire events due to device limitations such as weight and fixed air capacity. Biomass smoke is a variant, complex heterogeneous mixture of predominantly fine carbonaceous aerosols [3]. However, the monitoring of $PM_{2.5}$ can be utilized as a marker of smoke exposure [4].

Prescribed fires (Rx) are managed fires used in forest management, restoration of vegetation, and farming to reduce the accumulation of dry biomass fuel and lessen the likelihood of fast-spreading wildfires. Utilizing Prescribed fires enabled occupational monitoring without interference of job tasks or safety of the firefighters or research team.

***The objective of this work were to:***

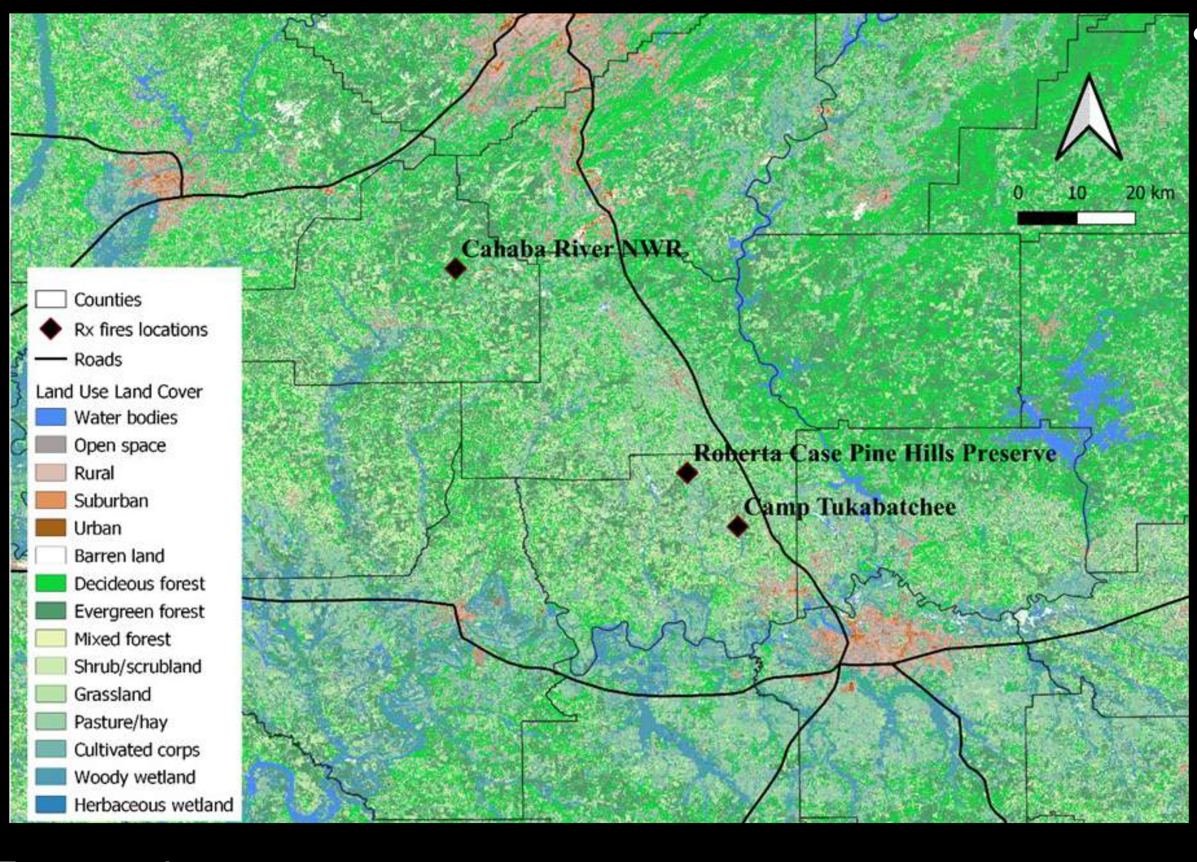
*1. Measure personal particulate matter (PM) exposure concentrations and size distribution during active Rx fire events.*

*2. Determine the spatiotemporal variation of personal exposures of firefighters to smoke aerosol during active Rx fire events.*

## METHODS

Study Location and Participants:

- Firefighters were recruited from The Nature Conservancy Rx crews.
- Measurements were obtained from 29 unique individuals over multiple Rx events resulting in 81 individual person exposure measurements
- Fires were conducted across three locations in central Alabama (Figure 1) that were comprised predominantly of longleaf pine forest
- Fires were ignited by heavy drip torch and re-ignited as necessary throughout the burn events to maintain and promote advancement of the fire front resulting in mixed flaming and smoldering conditions.




Exposure Assessment:

- Portable laser particle counting monitors (Dylos 1700) were attached near the breathing zone to the shoulder-pads of line-gear (packs) of each participant and worn throughout the work shift to determined personal exposures to particle number concentration (PNC) and size distribution.
- Small, portable GPS devices (Garmin e-Trex 10) were carrying within the line-gear for each firefighter to record the location, altitude, speed, and distance traveled throughout the work shift.

## RESULTS/DISCUSSION

Table 1: Average 1-minute personal exposure concentrations to PNC (median (μ) and min-max) of firefighters in Rx events

| *Particle number concentration (part $L^{-1}$) [$R_x$ fires]* | | |
|---|---|---|
| **Variable** | **μ (min-max)** | **σ** |
| Fine PNC (0.5-2.5 μm) | 19,545 (3-216,876) | 219.9 |
| Coarse PNC (>2.5 μm) | 1,411 (3-190,419) | 482.1 |

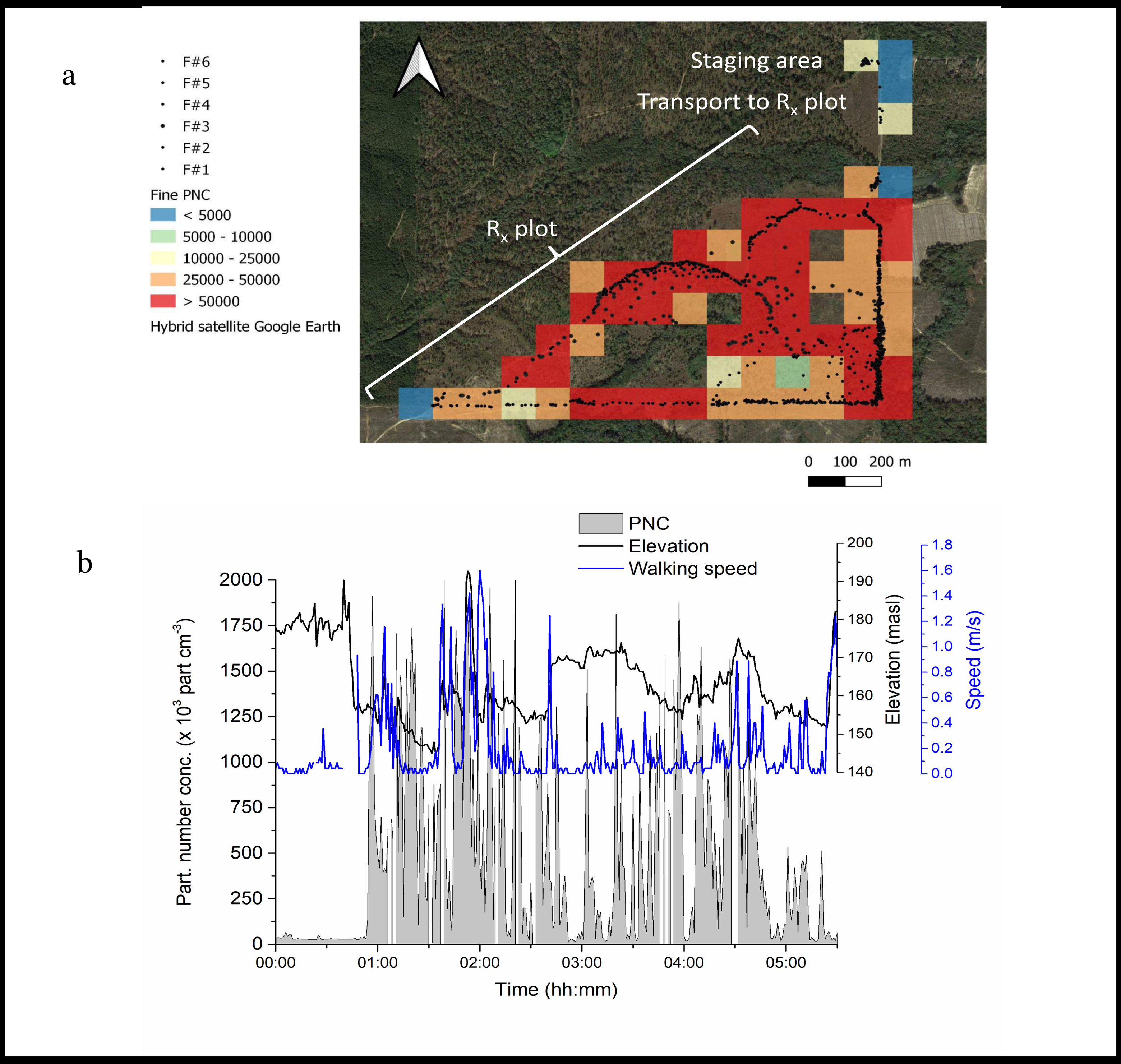



Figure 2. (a) Gridded average fine PNC and the locations of firefighters during Rx #12 and (b) representative 1-minute fine PNC concentration and movement (walking speed and altitude) of a participant in Rx fire #12

**Summary of Results:**

- Table 1: Personal exposures to fine and course PNC ranged from 3 to 216,876 particles/min and 3 to 190,419 particles/min respectivley. The fine PNC accounted for more than 70% of total (fine+course) particle number and showed high variability between participants.
- Figure 2a: Geospatial distribution showed high variability of fine PNC personal exposures (depicted by the color scale) indicating highly variable exposure patterns within the unit. Firefighters spent time (black dots) along the perimeter as well as within the perimeter of the burn unit. Low or moderate PNC were more commonly associated with standing along the fire boundary.
- Figure 2b: Temporal distrtibution showed high temporal variability where there is a delayed changes in PNC, walking speed and elevation between initiation of monitoring and fire ignition indicating exposures predominantly occurred after ignifiton of burn unit. Higher personal fine PNC were associated with increased walking speed while ascending or descending elevation indicating higher exposures during periods of elevated activity.

## CONCLUSIONS

- Rx wildland firefighters real-time personal exposures to smoke aerosol were assessed over multiple Rx events.
- Personal PNC were predominantly in the fine size range and showed high special-temporal variability throughout events (temporal and spatial) and between participants.
- Higher fine PNC were measured during elevated activity and within the burn unit perimeter.

Future Work:

- Determine influence of other physical burn unit factors influencing personal PNC generation
- Investigate spatial-temporal patterns of fine PNC exposure and cardiovascular health response

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# Thermal Response Determination of Buckypapers During Photothermal Desorption

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## ABSTRACT

Recently, our lab developed a novel, pre-analytical technique known as photothermal desorption (PTD)[1], which uses pulses of visible light to desorb analytes from air sampler sorbents (i.e. buckypapers or BPs)[2], for the purposes of occupational exposure assessment. To better understand the desorptive capabilities of the PTD method, the range of BP temperatures achievable by the technique must be determined. In the present work, we sought to both measure the thermal response of BPs during PTD, and to determine the best method for conducting such measurements.

Using arc discharge, single-walled carbon nanotubes, BPs were fabricated and exposed to 4 different energy densities in the range of 0.28 to 1.33 J/cm$^2$, produced by pulses of visible light during PTD, and the resulting peak temperatures were obtained using a fast response (150 to 200 ms) thermocouple (T/C) mounted to each BP using various means (i.e. pressed, adhered, and embedded).

BPs measured using pressed and adhered T/Cs resulted in average peak temperatures ranging from 29.1 to 50°C and 25.2 to 56°C, respectively, while embedded T/C measurements ranged from 35.2 to 76°C.Additionally, the embedded BPs measured temperatures that were 74 to 86% of the input temperature from the lamp, while the pressed and adhered BPs measured 48 to 71% and 54 to 71%, respectively.

From the data presented, it is clear that measuring BP thermal response is best performed with an embedded T/C, as this method recorded both the highest peak temperatures and the temperatures most similar to those input by the lamp, when compared to adhered and pressed T/Cs pulsed with the same energy densities.

## SITUATION/PROBLEM

- *Currently marketed diffusive samplers are a great means for conducting volatile organic compound (VOC) exposure assessments. However, their sensitivity is limited due to the small sample masses collected by diffusion, and the use of chemical desorption to collect and dilute samples from sorbent media.*
- Using PTD, we have removed the need for prep steps like chemical desorption, which allows concentrated samples to be directly analyzed, thereby increasing sensitivity, but there are still unknowns surrounding the desorption capabilities of PTD (i.e. what desorption temperatures can be produced).
- *Because of this, **The present work sought to investigate two main questions:***

1. What desorption temperatures can be achieved using PTD?

2. What is the best method for measuring said temperatures?

## METHODS

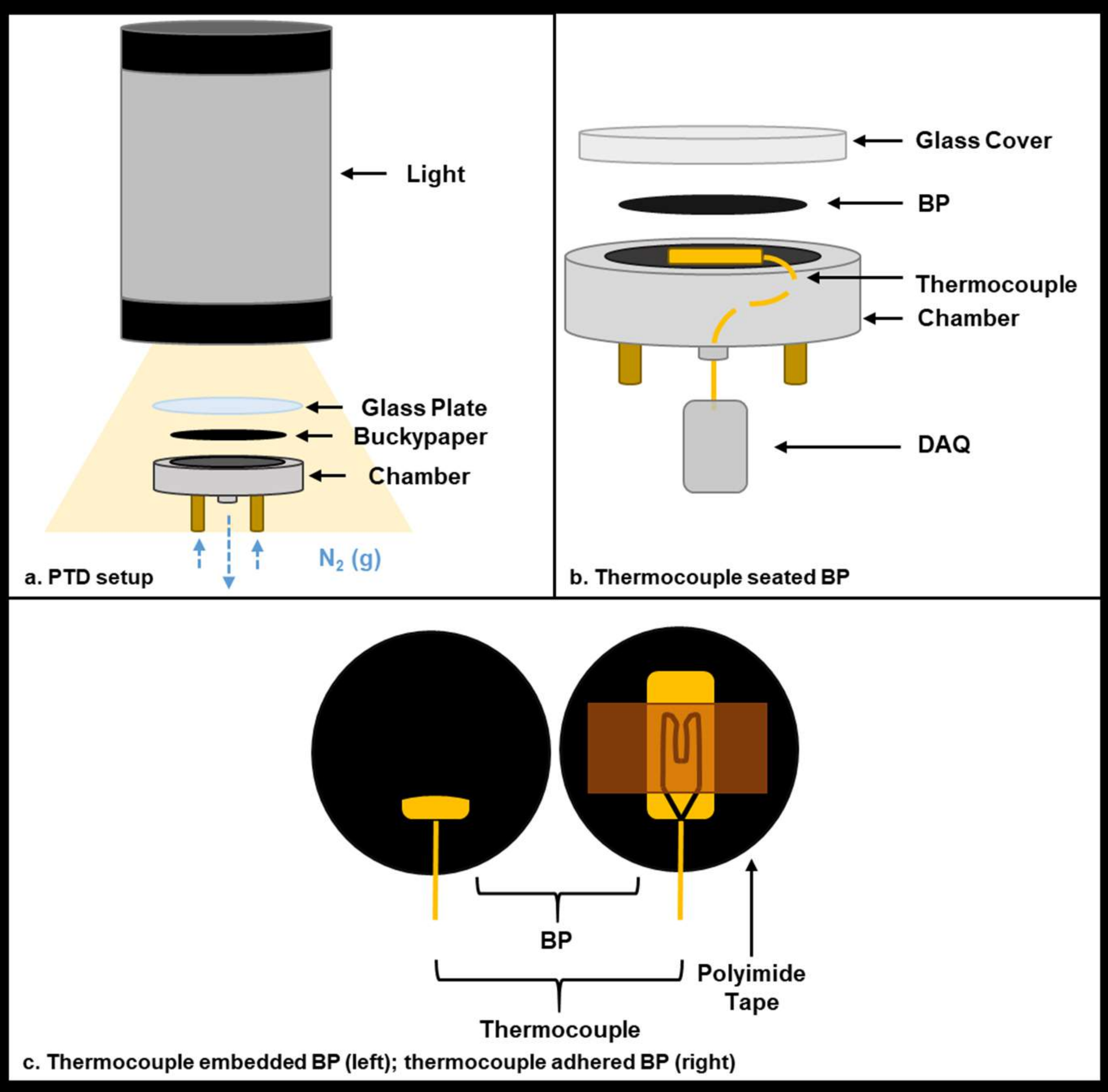


**Figure 1:** Setups for photothermal desorption and mounting methods.

- Using arc discharge, single-walled carbon nanotubes, BPs were fabricated and heat treated based on our previous works[3].
- BPs were exposed to 4 different energy densities ranging from 0.28 to 1.33 J/cm$^2$, produced by pulses of visible light during PTD (Figure 1a).
- The resulting temperature measurements were obtained using a fast response (150 to 200 ms) thermocouple (T/C) mounted to BP sorbents using one of three methods: pressing (P-BP), adhesion (A-BP), and embedding (EM-BP).
  - Pressed BPs were seated on the surface of a T/C, within the PTD chamber, and pressed into place by a glass cover (Figure 1b).
  - Similarly, adhered and embedded BPs were placed inside the PTD chamber, but physically attached to a T/C by either polyimide tape (i.e. adhered) or embedding during BP fabrication (Figure 1c).

## RESULTS/DISCUSSION

**Table 1:** Average buckypaper peak temperatures based on energy density and T/C mounting method

| Lamp Setting | Energy Density (J/cm$^2$)*† | Peak Temperature (°C)*‡ | | | P-Value** |
|---|---|---|---|---|---|
| | | P-BP | A-BP | EM-BP | |
| 3 | 0.28 ± 0.02 | 29.1 ± 0.9 | 29.2 ± 0.8 | 35.2 ± 0.9 | <0.0001 |
| 4 | 0.42 ± 0.01 | 32 ± 2 | 32.8 ± 0.7 | 41 ± 1 | |
| 5 | 0.728 ± 0.009 | 38 ± 3 | 40 ± 2 | 53 ± 1 | |
| 6 | 1.33 ± 0.01 | 50 ± 5 | 56 ± 3 | 76 ± 4 | |

*Values are depicted as mean ± standard deviation †n = 30; ‡n = 9; **α = 0.05

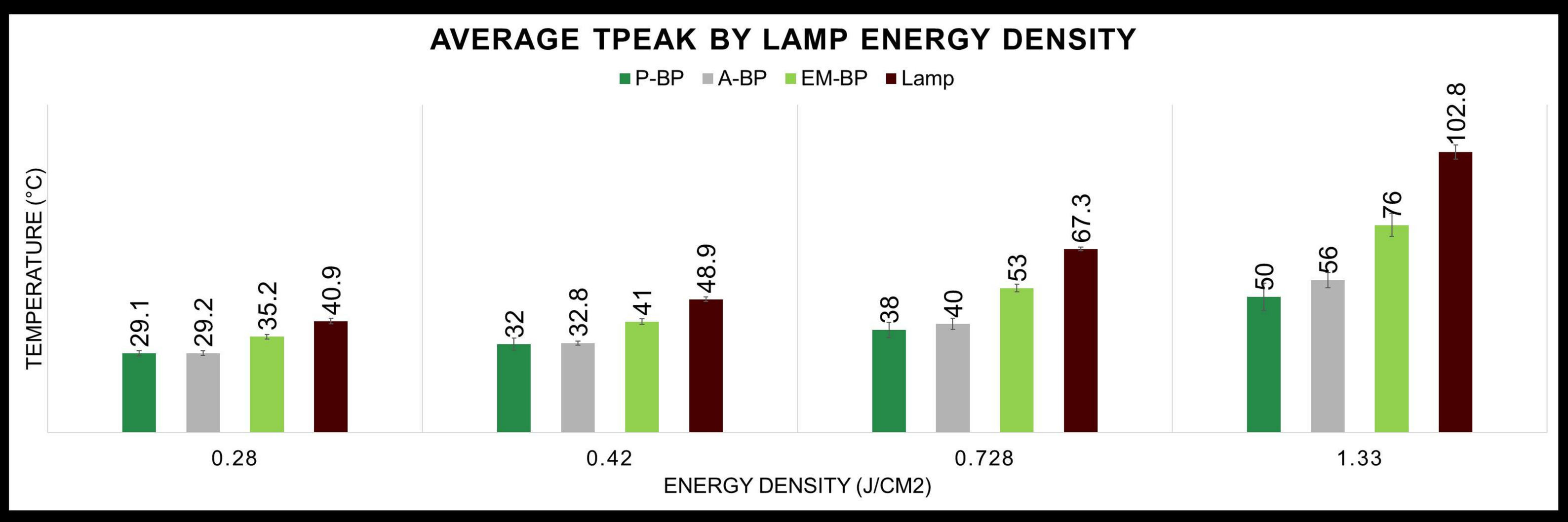


**Figure 2:** Average peak temperatures measured by each thermocouple attachment method (P-BP, A-BP, and EM-BP), compared to the input temperatures generated by the lamp alone, over varying lamp energy densities

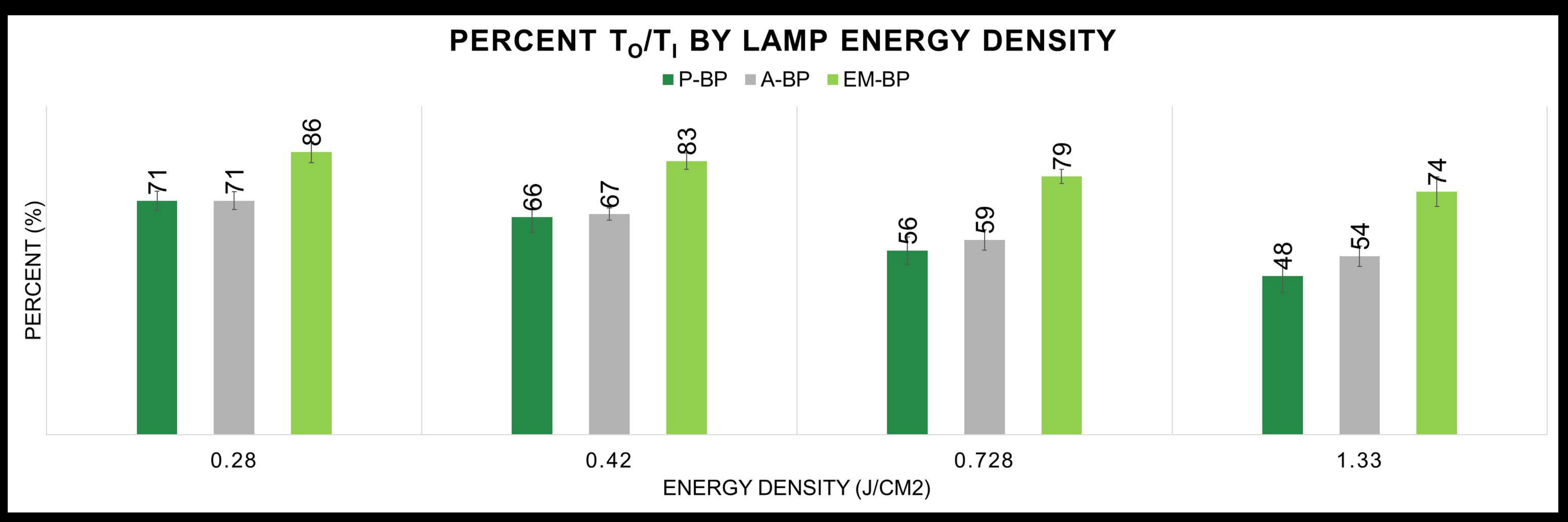


**Figure 3:** Comparison of the average percent of output temperature ($T_O$) measured from the BPs over input lamp temperature ($T_I$) across all three thermocouple attachment methods, over varying lamp energy den-

**Summary of results:**

**Table 1:** BPs measured using a thermocpuple with and without adhesion resulted in average peak temperatures ranging from 25.2 to 56ºC and 29.1 to 50ºC, respectively, while embedded T/C measurements ranged from 35.2 to 76ºC

**Statistics:** Multiple linear regression model ($R^2$ = 0.91)

peak temperatures are statistically different across all measurement methods and energies

Tukey's test – Pairwise comparisons

- Embedded BP (EM-BP) 11.8ºC higher than adhered BP (A-BP) (95% CI = [9.4, 14.1])
- EM-BP 14.0ºC higher than pressed BP (P-BP) 95% CI = [11.7, 16.3])

**Figures 2 & 3:** Embedded BPs measured temperatures that were 74-86% of the input temperature on the lamp, while the pressed and adhered BPs measured 48-71% and 54-71%, respectively

## CONCLUSIONS

- The presented data demonstrate that quantifying BP thermal response is best achieved with an embedded T/C
- EM-BPs recorded both the highest peak temperatures and the temperatures most like those input by the lamp, when compared to adhered and pressed T/Cs pulsed with the same energy densities
- Additionally, the data show that PTD is capable of producing temperatures ranging from 35.2 to 76ºC

Future Works:

- Determine how well BPs adsorb various VOCs, in order to determine their range of use as an air sampling media
- Design a diffusive air sampler prototype to be used with PTD
- Characterize the uptake rate of prototype samplers and test with PTD

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