Introduction

Computer models that are used for day-to-day fire management are largely empirical (Rothermel 1972); examples include BEHAVE(Andrews 1986), Farsite (Finney 1998). Wildland fire researchers have recognized the benefit of insitu measurements of fire intensity and behavior as one critical component of efforts to develop improved fire decision support models. Actual measurements of fire intensity benefit wildland fire behavior research and modeling by providing data for evaluating and developing fire models. Past measurements consisted primarily of observations of rate of spread, gas temperatures and fuel consumption and have been both field based (Fons 1946; Barrows 1951; Cheney *et al.* 1993) and laboratory based (Fons 1946; Rothermel 1972; Catchpole *et al.* 1998) . Such studies provided useful data and observations; however with the advent of modern numerical computers, the complexity of wildland fire models has increased (Call and Albini 1997; Linn *et al.* 2002; Mell *et al.* 2007). New mathematical models include additional physics which led to the need for additional measurements, particularly of the basic heat and chemical processes occurring in fire. This need has been addressed through both field (Alexander 1990; Stocks *et al.* 2004; Hiers *et al.* 2009) and laboratory experiments (Catchpole *et al.* 1998)

However quantitative measurements of energy and mass transport in wildland fire have been relatively sparse. The reasons are likely related to the risks and hazards to humans and equipment associated with wildland fires as well as the high degree of uncertainty in the weather and fuel conditions. Additionally, only recently has the technology become readily available at a cost that allows scientists to capture the desired measurements over the range of possible conditions. Some studies have been published that focus on relating fire intensity to emissions (Ward and Radke 1993), others on statistical modeling of fire behavior (Stocks *et al.* 1989).

For burns conducted at Fort Jackson a field deployable, fire resistant, programmable sensor array mounted in a fire resistant enclosure and coupled with a video imaging system was used to characterize energy release from flames. The sensor system was been coupled with a digital video system.

Two enclosures comprise the system. The primary sensor package is termed the Fire Behavior Flux Package (FBP). It measures 27 cm by 15 cm by 18 cm and in its current configuration weighs approximately 5.3 kg (fig. 1). Various enclosure materials have been used from mild steel, stainless steel and aluminum, the latest design consists of 3.7mm thick aluminum welded at the seams. A 12 volt 2.2Ah sealed lead acid battery or 8 AA dry cells provide power to the logger. The dataloggers used are Campbell Scientific® model CR1000. The dataloggers are capable of logging over one million samples, providing 20 hours of continuous data logging at 1hz. This logger is user-programmable and accepts a wide range of analog and digital inputs and outputs. It is thermally stable and has been relatively insensitive to damage incurred in shipping and handling. The second part of the system is a fire proof enclosure housing a video camera and is termed the In-situ Video Camera (IVC). The IVC measures 10 cm by 18 cm by 19 cm and is constructed of 1.6 mm aluminum with a weight of approximately 1.8 kg (fig. 2). The front of the IVC has two circular windows nominally 45 and 20 mm in diameter. A double lens configuration of high temperature pyrex glass and a second lens of hot mirror coated glass (Edmund Optics) is mounted in the ports. This multi-layer dielectric coating reflects harmful infrared radiation (heat), while allowing visible light to pass through. Both the FBP and IVC are designed to be mounted tripods. The preferred tripods consist of wall galvanized 2.5 cm diameter mild steel pipe with one extendable leg to facilitate deployment on slopes. Once mounted on the tripods a layer of 2.5 cm thick ceramic blanket enclosed in a single layer of fiberglass reinforced aluminum foil is wrapped around the boxes to provide further thermal protection. The packages are typically deployed so that the sensors are directed towards the oncoming fire front. The FBP is oriented to "look" at the expected fire approach direction, while the IVC is positioned to image both the FBP and approaching fire front (fig. 3). Once the FBP and IVC's are mounted on tripods, they are powered up. The FBP's have LED's to indicate that the logger is indeed running, the IVC's also have an LED to indicate that they are running and have entered "sleep" mode when they are being used with the remote automatic trigger system.

During the burns at Fort Jackson sensors and cameras were deployed for burns 1-7 (Figures 1-11). Across all burns average total energy incident at the face of the sensor was 8.3 kW/m^2 with an average maximum of 17 kW/m^2 (Figure 12). Average radiant flux was 4.4 kW/m^2 with an average peak value of 10.4 kW/m^2 (Figure 13). Convective heating the sensor face can be extracted by accounting for transmission through the radiant window and correcting for the difference between the total and radiant heating levels. Using this method average convective heating the surface of the sensors was 5.2 kW/m^2, with peak average value of 9.6 kW/m^2 (Figure 14). Average air temperature at the sensor location 473 C with an average peak of 743 C (Figure 15). Average vertical air velocity at the sensor location was 1.8 m/s while average peak velocity for all burns was 3.7 with average downward velocity of -.13 m/s (Figure 16). Similarly average horizontal velocity into the face of the sensor was 1.2 m/s with average peak of 3.9 and minimum of -2 m/s (Figure 17). From an individual burn point of view burns 2, 4 and 7 produced the highest heating and temperatures. The overall peak energy level recorded was nearly 30 kW/m^2 of total heating for burn 2.

These heating values are representative of those reported elsewhere for similar vegetation and environments (Frankman *et al.* 2013). They are quantitatively at the low end of the energy release spectrum and suggest that burning conditions were largely low intensity. Impacts to surrounding vegetation and soil would be expected to be low.

Figure 1 Fire behavior package 6 set up for burn 1.

Figure 2 Fire behavior package 6 during burn 1. This package saw a peak total heat flux of 10.9kW/m^2, peak air temperature of 423°C, and registered a peak wind speed of 3 m/s.

Figure 3 Fuel loading on burn plot 2. A peak total heat flux of 30kW/m^2 was registered for this burn along with a peak air temperature of 1042°C and a peak horizontal wind speed of 4m/s.

Figure 4 An example of fuel loading in the burn 3 plot.

Figure 5 Fire behavior during burn 3 where a peak total heat flux value of 17.5kW/m^2 was registered along with a peak air temperature of 954°C and peak wind speed of 4.5m/s.

Figure 6 A sensor package set up to monitor fire behavior in the reference plots of burn 4.

Figure 7 Fire behavior in the reference plots of burn 4. Instruments registered a peak total heat flux of 19.3kW/m^2, a peak air temperature of 714°C, and a peak horizontal wind speed of 3.6m/s.

Figure 8 Instrumentation set up to monitor fire behavior in burn 5 reference plots.

Figure 9 Fire behavior in burn 5 reference plots. A peak total heat flux of 10.9kW/m^2 was registered for burn 5 along with a peak air temperature of 511°C, peak horizontal wind speed of 3.8m/s.

Figure 10 Fuel loading in plot 6. A peak total heat flux of 12.4kW/m^2 was registered along with a peak air temperature of 631°C and peak horizontal wind speeds of 4m/s.

Figure 11 Fuel loading for plot 7. A peak total heat flux of 17.8kW/m^2 was registered along with a peak air temperature of 930°C and peak horizontal wind speeds of 4.3m/s.

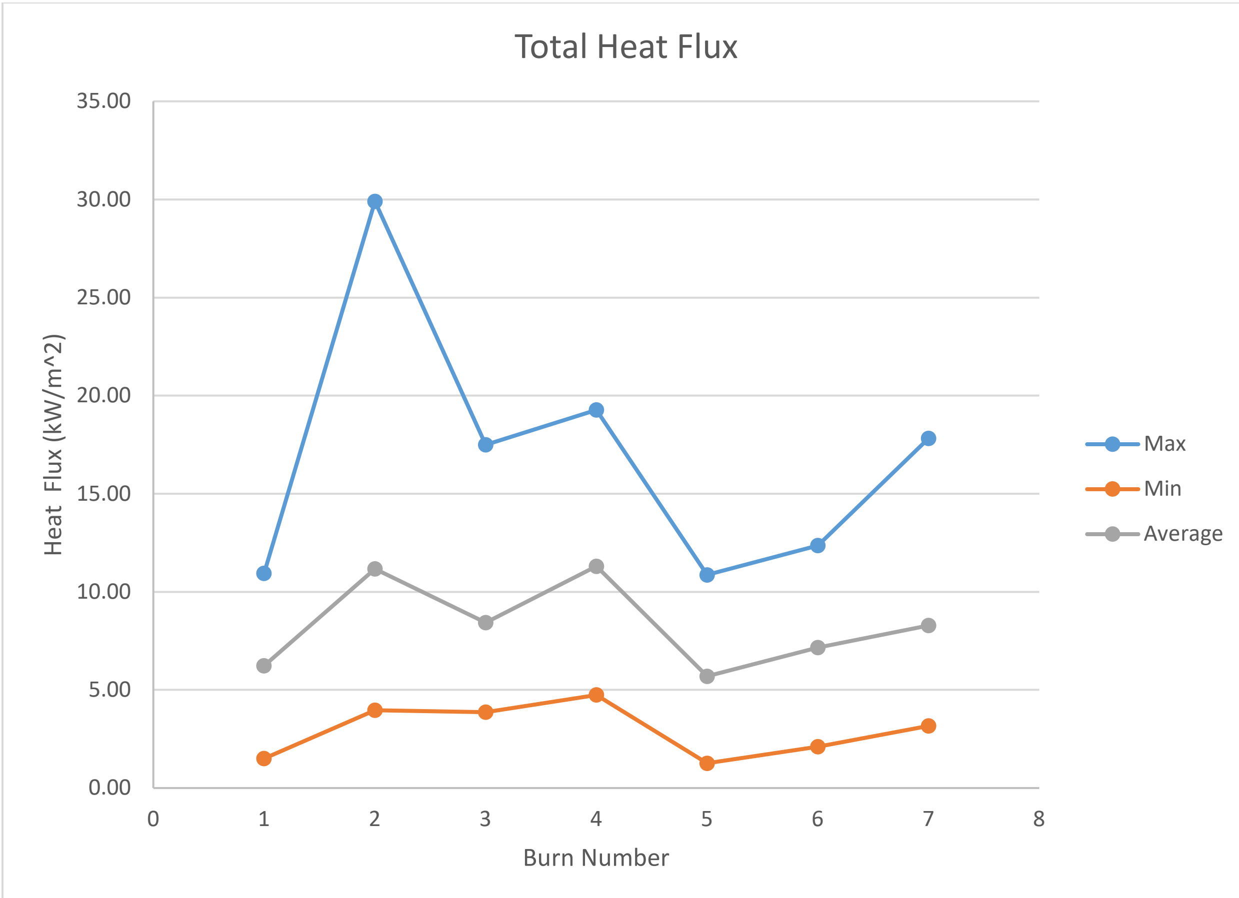
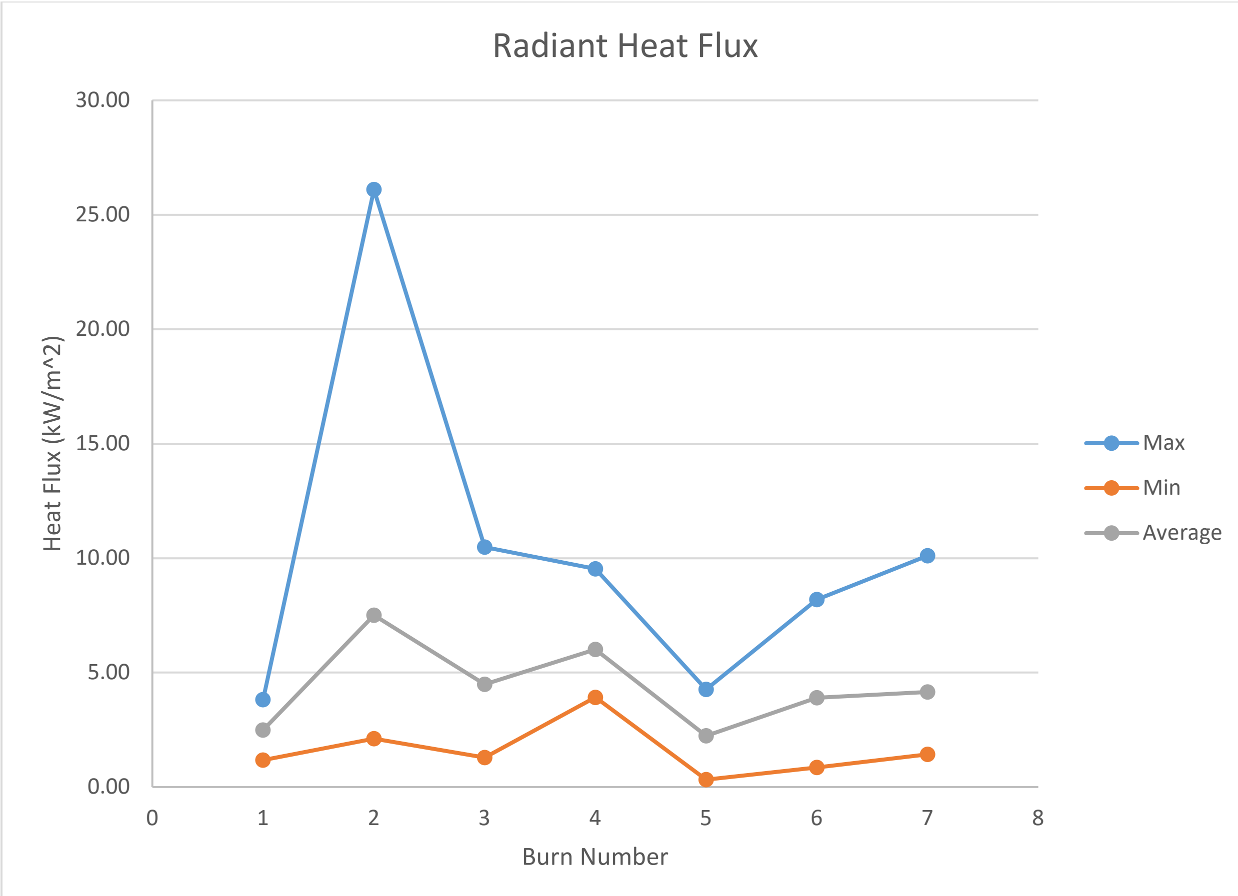
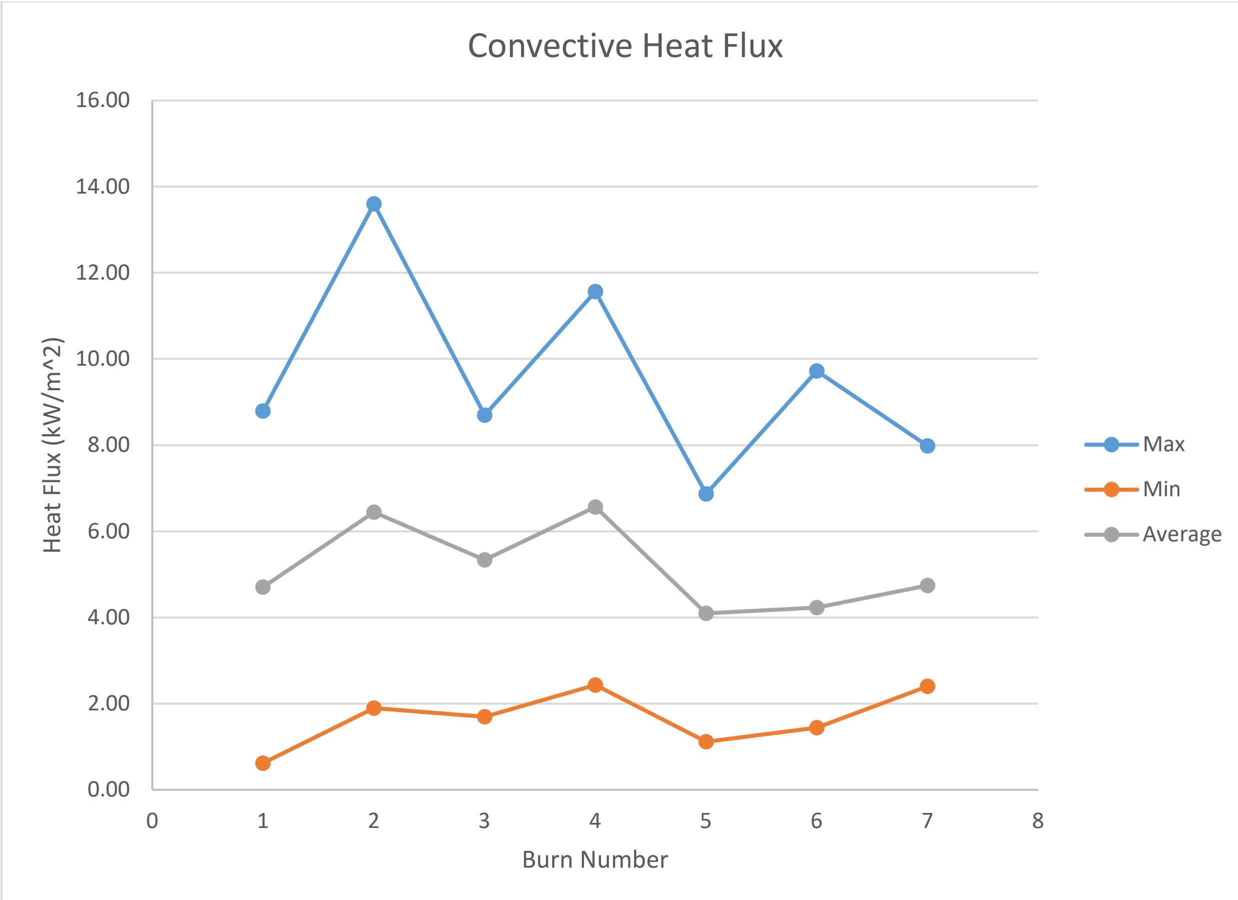

Total Heat Flux
Heat Flux (kW/m^2)
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0
1
2
3
4
5
6
7
8
Burn Number
Max
Min
Average

Figure 12



Radiant Heat Flux
Heat Flux (kW/m^2)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0
1
2
3
4
5
6
7
8
Burn Number
Max
Min
Average

Figure 13



Convective Heat Flux
Heat Flux (kW/m^2)
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0
1
2
3
4
5
6
7
8
Burn Number
Max
Min
Average

Figure 14

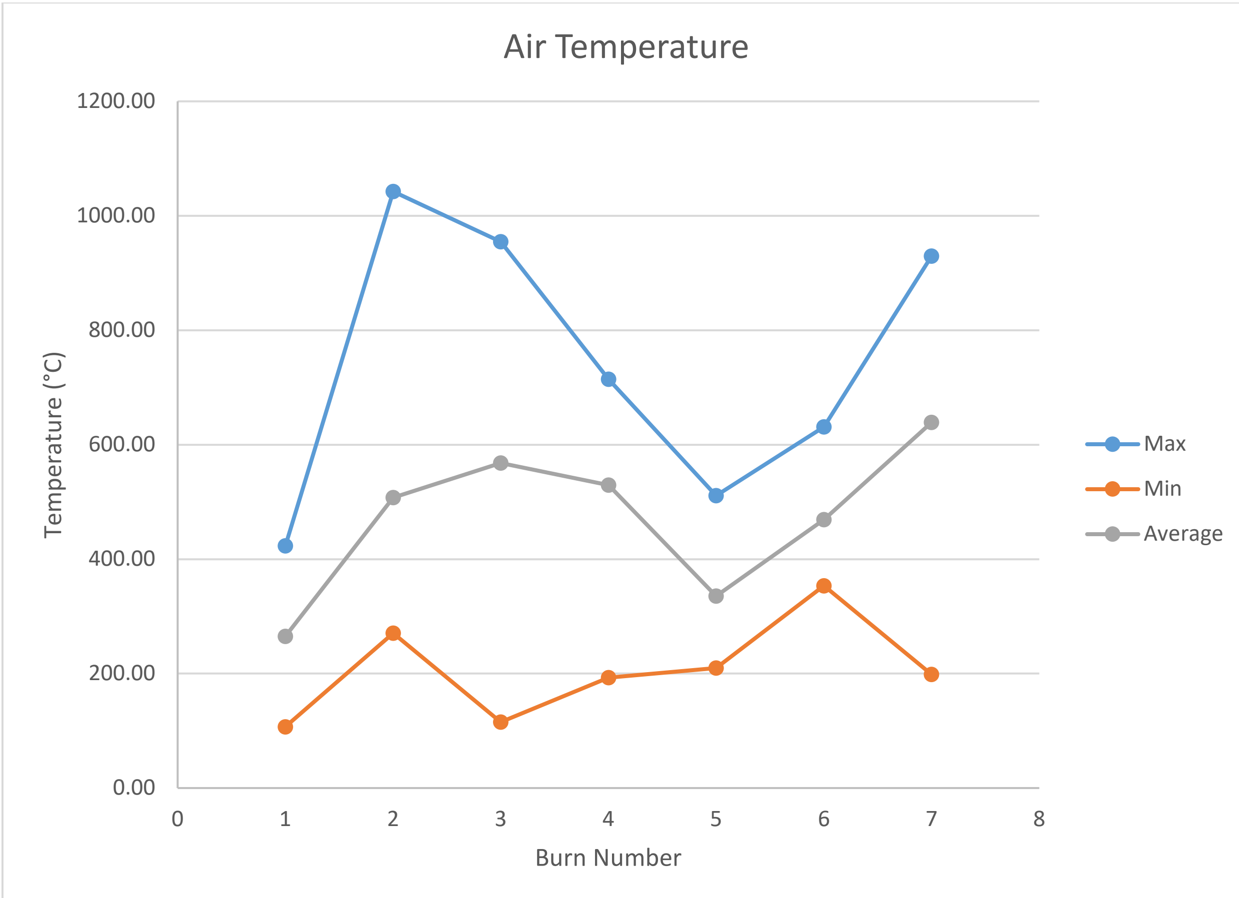

Air Temperature
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
Temperature (°C)
0
1
2
3
4
5
6
7
8
Burn Number
Max
Min
Average

Figure 15

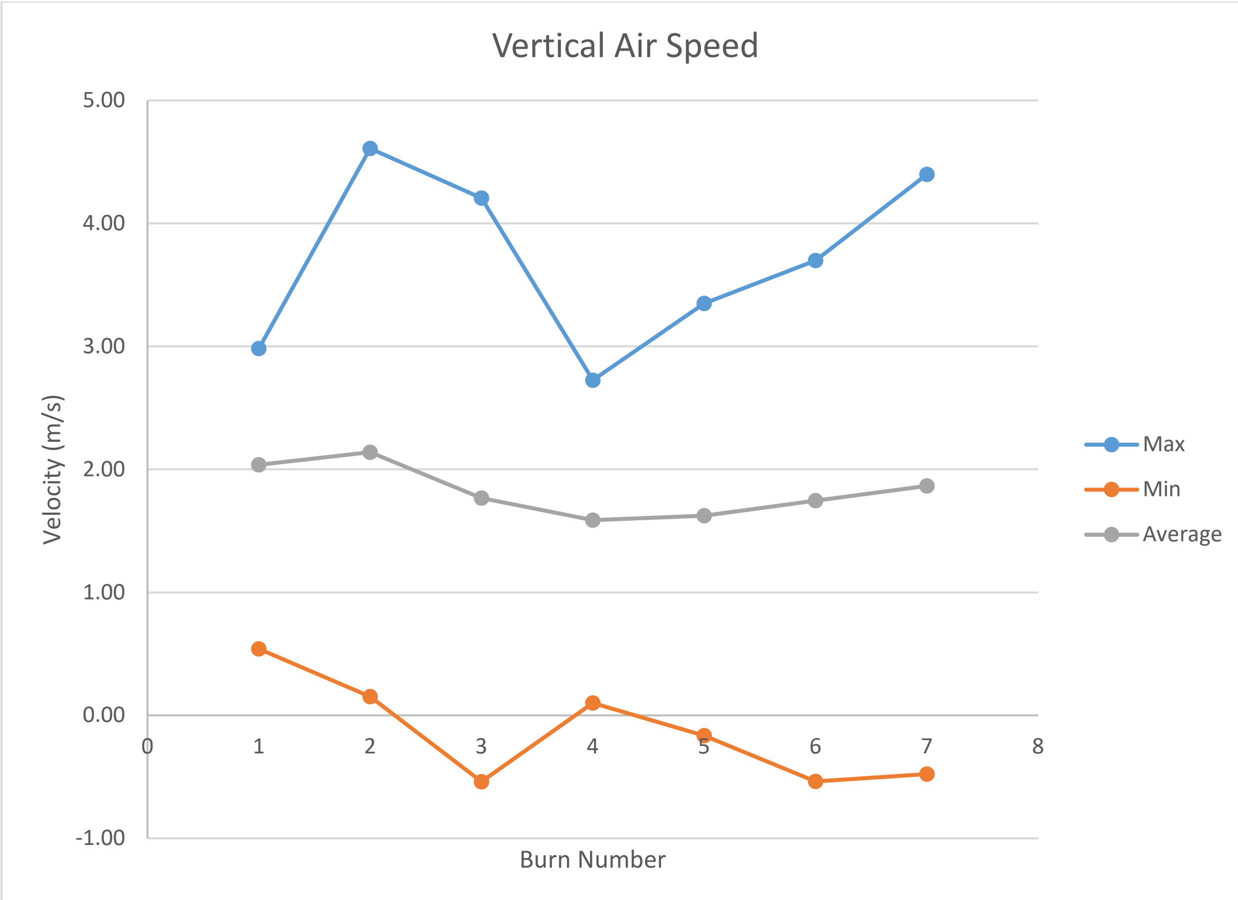


Figure 16 Positive vertical air speed is in the up direction.

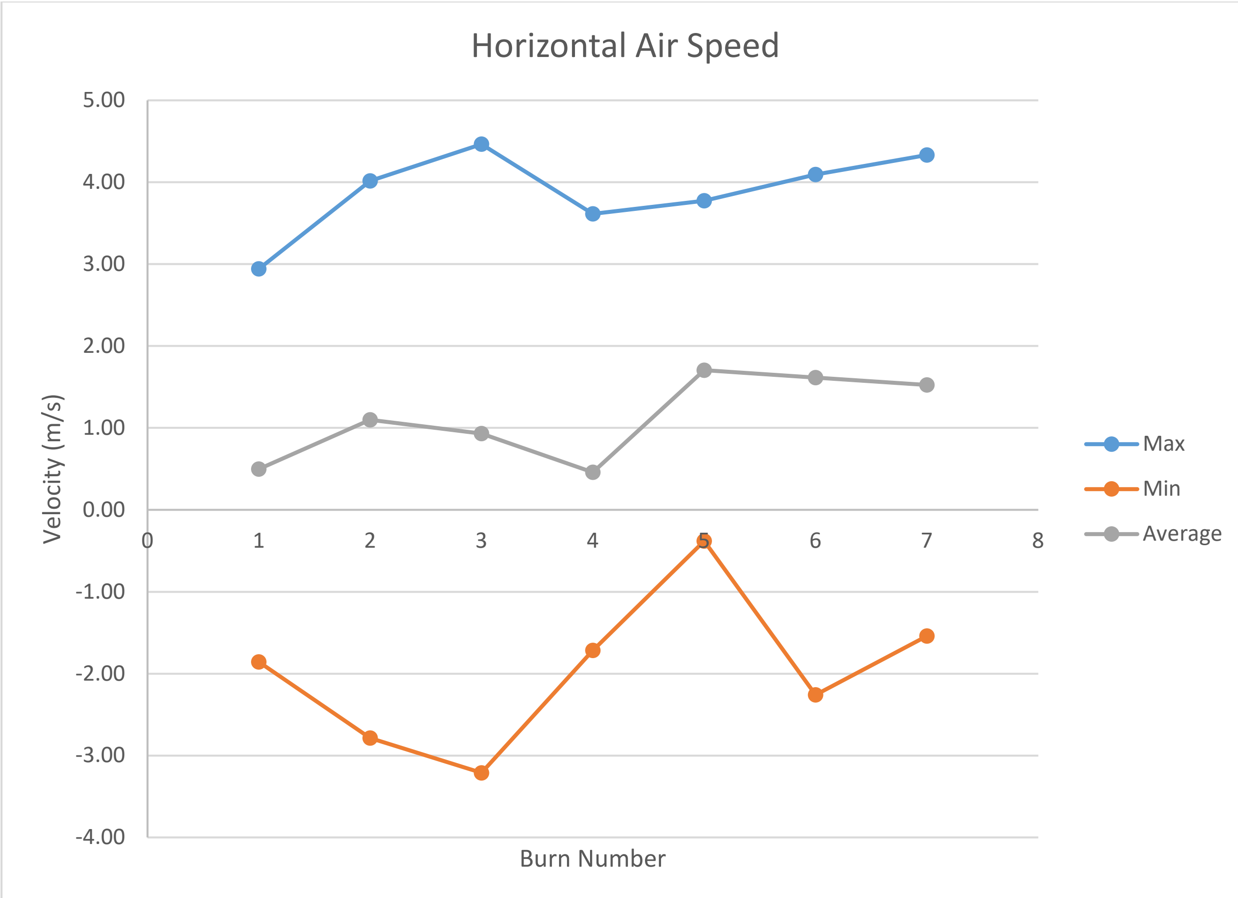


Figure 17 Positive horizontal air speed is into the face of the sensor package.

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