				26.52				
				30.3				
				27.92				
				29				
				32.4				
				18.34				
8.88	11.7	19	23.18	9.6	29.2	23.2	14.88	12.26
		8.6	8.8	8.88	8.8	8.8		
				Window				

Figure 4.3.3-7. Water distribution results for solid stream discharged into window opening (kg), the gray area does not contain a measurable amount of water.

5 Structure Fire Experiments

Prior to each fire experiment, the Large Fire Facility pollution abatement system was started and set for exhaust at full capacity, approximately 42,000 l/s (90,000 SCFM). The data acquisition systems were started and the oxygen consumption calorimetry system and gas measurement instruments were calibrated by setting the "zeros" and "spans" of each instrument with certified calibrated span gases. The computerized data acquisition systems then collected background data and continued to collect data from each sensor at a rate of one reading per second until the end of the experiments. The temperature and heat flux sensors were also exposed to a small heat source prior to each experiment to ensure functionality.

The fan was turned on and calibrated through a range of speeds from 800 rpm to 2500 rpm to serve as a daily check of the pressure transducer readings from the locations throughout the structure. After the fan speed for the test was set, the wind condition was then measured at the bedroom window opening, and then the fan was turned off. The window glass was installed in the bedroom window. Once the window was in place, the fan was turned on and after at least one minute of background data was collected, the video cameras were started and video time was synced with a light flash. Once all measurement devices were verified to be recording, the countdown for ignition began. The trash container with approximately 0.3 kg (0.7 lbs)of newspaper, as described in the heat release rate experiment section, was ignited remotely with an electric match. The trash container was positioned between the west side of the bed and side of an upholstered chair as shown in Figure 5-1.

Figure 5-1. Photograph of the placement of the trash container fuel package ignition source.

After ignition, the fires grew unaided. The fires continued to grow and eventually transferred enough energy to the 6 mm (0.25 in) thick window glass to cause it to fail, either a crack or an opening created by cracking glass. After window failure, a researcher in a firefighter personal protective ensemble (PPE), would clear out the remaining pieces of glass so that the effective window opening size would be consistent for each experiment. Then the fire was observed until it appeared that it had spread through the structure and untenable conditions, even for a fully protected firefighter, existed in the corridor portion of the structure. Then, the mitigation tactics were employed, and ultimately the fire was suppressed.

Table 4.3-1. shows a brief description of the eight structure experiments that were conducted. The results of each of these experiments will be discussed in the subsequent sections.

Table 4.3-1. Table of Structure Fire Experiments

WDF Test	Experiment Description
1	Baseline, No Wind
2	Large wind control device
3	Large wind control device
4	Small wind control device, low flow window nozzle
5	Small wind control device, low flow window nozzle
6	No WCD, fog nozzle, hand line
7	No WCD, 15/16 in smooth bore, hand line
8	No WCD, 15/16 in smooth bore, hand line

5.1 Baseline Experiment (WDF1)

The first fire experiment in the structure was different from the other experiments in that no external wind was being imposed to the structure. In this experiment the door between the hall and the target room was a hollow core wood door. The trash container was remotely ignited and the fire was allowed to grow. After the window was broken (vented) by the fire, a researcher in full PPE cleared the window opening with a pike pole. After the window was vented, the fire was given time to respond to the change in ventilation. After the fire within the structure was determined to be fully developed, the fire was then suppressed by safety sprinklers installed in the structure and by a manual hose stream. A timeline for the experiment is presented in Table 5.1-1.

The results for the experiment are presented in the following sections: observations, heat release rate, temperature, heat flux, pressure, velocity, and gas concentrations. An uncertainty range marker is included in each graph.

Table 5.1-1. Experiment 1 Timeline

Time (s)	Event
0	Ignition
60	Visible smoke layer
213	Partial window failure (pieces missing)
248	Window vented Manually
268	Hot gas flow to floor in corridor IR
348	Target room door fails
493	Begin suppression

5.1.1 Observations

The observations are presented as a series of images captured from eight camera locations, six were video cameras and two were thermal imaging cameras. The camera positions are shown in Figure 4.1.3-1.

Figure 5.1.1-1 through Figure 5.1.1-11 present sets of eight images, one from each camera position, at a given time, from the time of ignition to 540 s after ignition. Each image view is labeled. The first four views at the top of each figure show the west wall and window of the structure and then follow a path through the interior of the structure with a view of the bed room, the living room and a view (looking west) through the open door to the corridor. The second set of four views, at the bottom of each figure, provides a video view of the north east portion of the corridor and a view of the inside of the target room door. The thermal imaging cameras provide a view of the east corridor, looking north, and a view of the inside of the target room.

Figure 5.1.1-1 shows the conditions at the time of ignition. At this point, the six video views are clear and unobstructed. However, the thermal images provide limited thermal contrast, because the surfaces in the view were at nearly equal temperature.

The images in Figure 5.1.1-2 were captured 60 s after ignition. The fire from the trash container spread to both the bed and the upholstered chair. A smoke layer formed in the bedroom, and the ceiling jet started to move down the hall. There was no smoke or change in thermal condition in the living room, target room or corridor at this time.

The images in Figure 5.1.1-3 were recorded at 120 s after ignition. The area involved in fire between the bed and the chair increased in size. The smoke layer was approximately 1.2 m (4 ft) thick throughout the bedroom, hall and living room. Smoke and heat had just started to flow into the corridor. The target room appears clear of smoke, however the target room IR view shows some heat infiltration along the top edge of the door between the hall and the target room.

Figure 5.1.1-4 shows the images recorded 60 s later at 180 s after ignition. The flames in the bedroom appear to have reached the ceiling. The smoke layer had continued to increase in thickness and was approximately 1.5 m thick (5 ft) in the bedroom, hall and living room at this time. The smoke layer was nearly as thick in the corridor. More heat and smoke was exiting the living doorway into the corridor, though the heat layer was well stratified and distinct from the lower layer of ambient air. Smoke has started to flow around the top portion of the hall door into the target room, this is reflected in the thermal image of the target room as well.

Figure 5.1.1-5 shows the conditions at 240 s after ignition. After flames had impinged directly on the upper north side corner of the window, a section of glass had broken out along the top edge of the window, which allowed smoke to vent out. The smoke layer had descended to the floor in the bedroom. This coated the lens of the bedroom camera, which obscured the view for the remainder of the experiment. The smoke layer was down to within 0.3 m of the floor in the living room and in the corridor. The heat in the corridor was still stratified. The video view of the door to the target room showed increased smoke flow into the target room. The thermal image of the target room door showed that the door was transferring heat.

As the flames continued to contact the north edge of the window, more glass along the north edge failed, however, the majority of the window glass remained intact. The window was manually vented beginning at 248 s after ignition and completed at 260 s after. Figure 5.1.1-6 shows the images recorded as the clearing of the glass was completed. The fire exiting the bedroom window increased in size as the glass was removed. The views in the bedroom, living room and corridor were obscured by smoke. The thermal image of the corridor shows that the heat flow out of the doorway had the most energy flow out of the top of the door, gradually becoming less intense nearer to the floor. A thin smoke layer, less than 0.3 m thick, had developed across the ceiling of the target room. More heat was flowing into the target room.

Figure 5.1.1-7 shows the images recorded at 300 s after ignition. Flames continued to flow out of the window opening. All of the images in the flow path from the window to the corridor vent were obscured by smoke or heat. Flames had started to burn through the top of the target room door and flames can be seen at the bottom of the door as well.

At 360 s after ignition, Figure 5.1.1-8 conditions in the bedroom appeared to have reached a steady-state, post-flashover, condition. All of the images in the flow path from the window opening to the corridor continued to be obscured. The target room showed the biggest change in conditions, as the wood hollow core door burned through and heat and smoke filled the target room.

Figure 5.1.1-9 and Figure 5.1.1-10 show conditions very similar to those recorded at 360 s after ignition. The fire in the bedroom continued as a post-flashover compartment fire as the flames pulsed out of the window opening. This continued until the safety sprinklers were activated at approximately 490 s after ignition. Suppression continued with a hose stream being applied through the window opening at 525 s after ignition.

The last set of images, Figure 5.1.1-11, was recorded at 540 s after ignition. At this point, the majority of the fire in the bedroom was suppressed. The dark areas, on the floor and the east wall of the corridor, in the corridor IR view are areas that were cooled by water from the hose streams that came through the living room doorway to the corridor.

Figure 5.1.1-1. Experiment 1, ignition.

Figure 5.1.1-2. Experiment 1, 60 s after ignition.

Figure 5.1.1-3. Experiment 1, 120 s after ignition.

Figure 5.1.1-4. Experiment 1, 180 s after ignition.

Figure 5.1.1-5. Experiment 1, 240 s after ignition.

Figure 5.1.1-6. Experiment 1, window fully vented, 260 s after ignition.

Figure 5.1.1-7. Experiment 1, 300 s after ignition.

Figure 5.1.1-8. Experiment 1, 360 s after ignition.

Figure 5.1.1-9. Experiment 1, 420 s after ignition.

Figure 5.1.1-10. Experiment 1, 480 s after ignition.

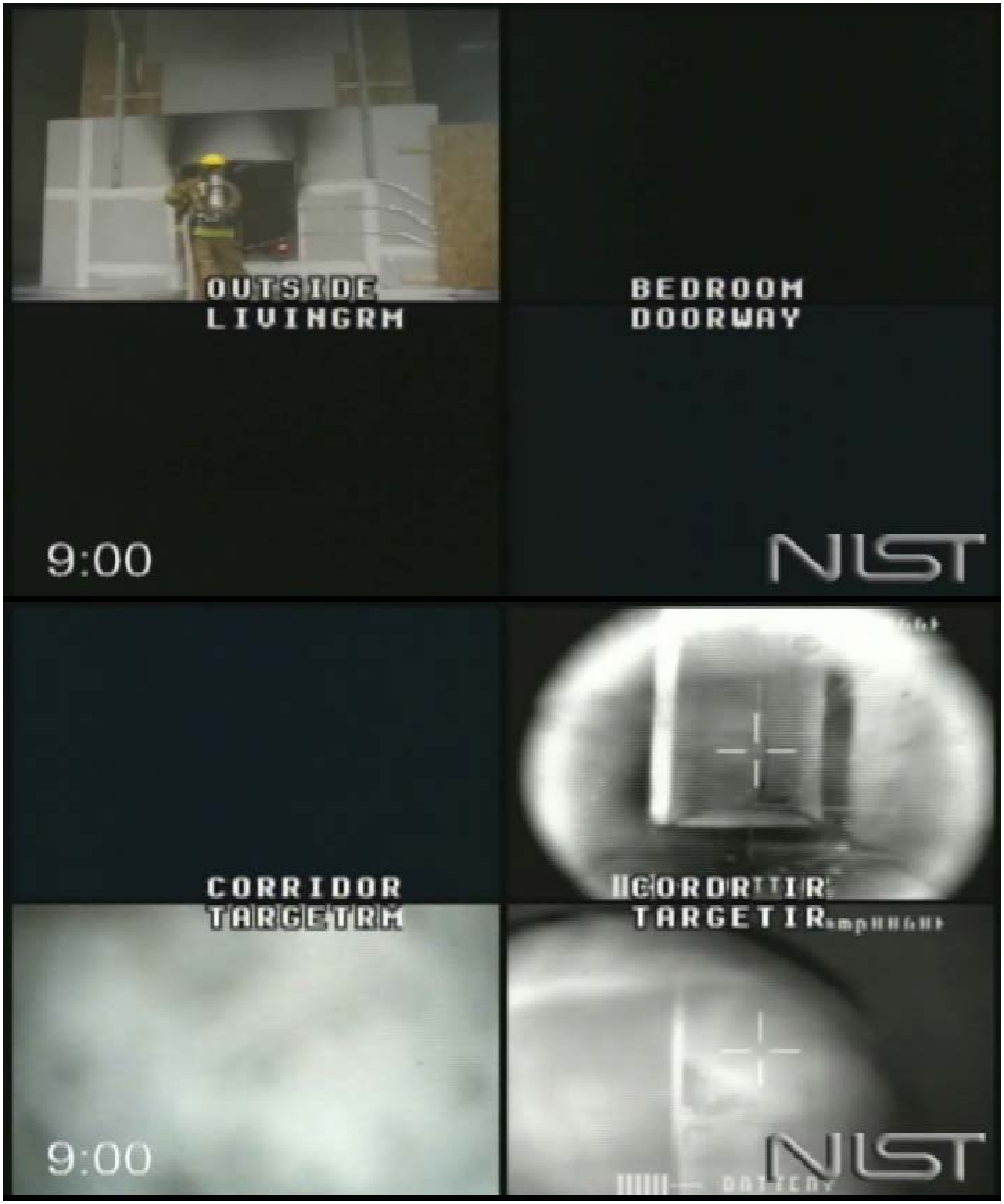

Figure 5.1.1-11. Experiment 1, 540 s after ignition.

5.1.2 Heat Release Rate

Figure 5.1.2-1 shows the heat release rate time history for Experiment 1. The measured heat release rate was zero for the first 150 s after ignition because the heat generated by the fire up to this time was contained within the experimental structure. After 150 s, the combustion products began to flow from the corridor vent into the oxygen consumption calorimeter. As the flow from the vent increased the heat release rate slowly increased to 1.5 MW. After the window was vented, the heat release rate increased from approximately 1.5 MW to 14 MW in less than 60 s. The heat release rate held steady between 12 MW and 13 MW for almost 180 s, then suppression was started.

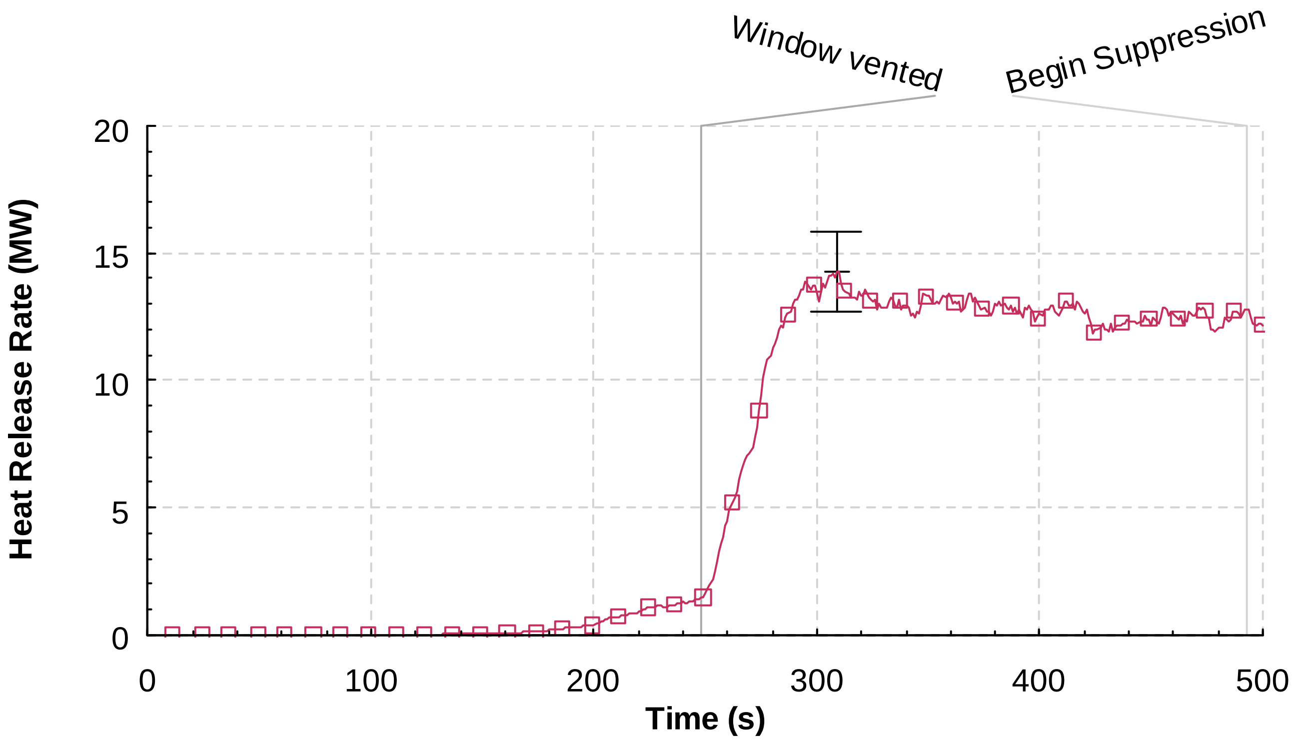

Figure 5.1.2-1. Heat release rate versus time, Experiment 1.

5.1.3 Temperatures

Figure 5.1.3-1 through Figure 5.1.3-11 provide the temperature measurements. The figures are given in order from the western most measurement point, the bed room window opening, and moving through the structure toward the east; bedroom, hall, living room, corridor, south and southwest portions of the corridor (closed end) and then to the north section of the corridor and ending with the exhaust vent. The last two temperature graphs have temperatures associated with the target room. The locations of the thermocouple arrays are shown in Figure 4.1.3-1.

The three thermocouples at the window, shown in Figure 4.1.3-1, provide insight into the ventilation profile in the window opening. The upper temperature trace shows a dramatic increase in temperature as flames came out of the upper portion of the window resulting in temperatures between 550 ºC and 850 ºC (1020 ºF to 1560 ºF). Temperature in the lower portion of the window only increased to approximately 100 ºC (212 ºF) due to the outside air being entrained through the lower section of the window.

Figure 5.1.3-2 shows the measurements from the thermocouple array located in the center of the bed room. A thermocouple was located 0.03 m (1 in) below the ceiling followed by thermocouples that were installed at approximately 0.3 m (1 ft) intervals until they were 2.13 m (7 ft) below the ceiling or 0.3 m (1 ft) above the floor. During the first 200 s, the data shows a temperature gradient in the bedroom ranging from 700 ºC (1290 ºF) near the ceiling to 100 ºC (212 ºF) at 0.3 m above the floor. As the window began to fail, the temperatures near the ceiling cooled by almost 100 ºC (212 ºF), while the rest of the thermal layer increased in temperature. Within seconds of the manual venting of the window at 248 s, the room went from a thermally stratified environment to a post-flashover (thermally well mixed) environment where temperatures at all elevations in the room were similar and in excess of 600 ºC (1100 ºF). This post-flashover condition continued until the fire was suppressed.

The measurements from the thermocouple array in the hall are shown in Figure 5.1.3-3. They followed a very similar trend to the bedroom data until the target room doorway began to burn. The burning of the door and the change in ventilation and flow due to the resulting opening between the target room and the hall, corresponded with the steady increase in temperatures staring at 350 s. This area also remained well mixed thermally post flashover until suppression.

Figure 5.1.3-4 and Figure 5.1.3-5 both show the temperature data from the living room. Figure 5.1.3-4 presents the temperature measurements from the thermocouple array in the SW corner of the living room, out of the direct flow path from the hall. From this set of temperatures it would appear that flashover did not occur in the living room, as a thermal gradient was maintained from the ceiling to within 0.3 m (1 ft) above the floor throughout the experiment. Although after 450 s it would appear that the layer was well mixed within 0.6 m (2 ft) of the floor. The spike in temperatures at approximately 350 s, may be related to the burning of the target room door or may be an indication of one of the larger items of furniture in the living room was burning. Unfortunately the cause of this temperature increase could not be determined from the videos.

Figure 5.1.3-5 shows the results from the thermocouple array that was in center of the room, basically in the flow path from the bed room to the vent in the corridor. Similar to the bed room and the hall, the timing and the trends are consistent, except the peak temperatures are lower and the temperatures at the different elevations in the room do not converge as well as in the other two spaces, which is consistent with a pre-flashover condition. These temperatures are higher than the temperatures in the SW corner of the living room. At 300 s after ignition, the temperatures in the center of the living room ranged from approximately 700 ºC (1300 ºF) near the ceiling to approximately 450 ºC (850 ºF) 0.3 m (1 ft) above the floor. In the corner position at the same time, the temperature ranged from 550 ºC (1000 ºF) 0.3 m (1 ft) below the ceiling to approximately 350 ºC (650 ºF) 0.3 m (1ft) above the floor. After 350 s, the thermal layer became well mixed from the ceiling down to at least 1.83 m (6 ft) below the ceiling.

Temperature conditions just outside the living room in the center of the corridor are given in Figure 5.1.3-6. They are very similar to those in the center of the living room, except the temperature closest to the floor was hotter perhaps due to recirculation from the closed portion of the corridor. This thermal time history also shows a change at approximately 350 s after ignition. It is not as pronounced as in the temperature data from the hall or the living room, however the effect was the same in the sense that after that time the range of the thermal gradient continued to become smaller as the area of the corridor just outside the living room became well mixed at approximately 600 ºC (1100 ºF).

Figure 5.1.3-7 and Figure 5.1.3-8 present the temperature readings from the thermocouple arrays in the south and southwest portions of the corridor. These two arrays are in the portion of the corridor that does not lead directly to a vent. Therefore any flow that may move into this section will have to reverse completely to flow to the north toward the open vent that leads to the exhaust hood. As a result, significant thermal gradients from the ceiling to the floor, were maintained throughout the experiment. All of the temperatures at both locations increased significantly within seconds after the window was vented. The temperature increases were less than those in the direct flow path.

There was a significant temperature difference, at the positions closer to the ceiling, between the south and the southwest locations. The southwest location was approximately 250 ºC (482 ºF) cooler at 0.3 m (1 ft) below the ceiling than the same thermocouple at the south position closer to the living room doorway. However the temperatures at 2.13 m (7 ft) below the ceiling were very similar at approximately 200 ºC (392 ºF).

Figure 5.1.3-9 displays the temperature data from the north corridor thermocouple array which is in the direct flow path between the living room doorway and the vent. Prior to the window being vented, the temperatures and the thermal gradient from the ceiling to the floor appear very similar to the temperatures measured at the south corridor position (Figure 5.1.3-7). However, after the window was vented the temperatures at the north corridor position increased at a faster rate than those at the south position. Approximately 430 s after ignition, the temperatures from the ceiling to 2.13 m (7 ft) below the ceiling were nearly equal. Just prior to suppression, the temperatures had peaked at approximately 650 ºC (1200 ºF).

The temperatures at the exhaust vent are given in Figure 5.1.3-10. These thermocouples are at the same elevation located 2.44 m (8 ft) above the ceiling of the corridor. The three thermocouples are spaced 0.51 m (1.67 ft) apart along the east-west centerline of the vent. These temperatures increased in a manner similar to those at the north corridor location, with the exception of the period from approximately 220 s after ignition to the time of window failure. For that brief period, it appears that the temperatures in the vent decreased, perhaps due to cooler air from outside the exhaust vent mixing with the combustion products which at that time had a low velocity. Post window failure time, the vent temperatures increased, again similar to the north corridor temperatures and peaked at approximately 600 ºC (1112 ºF).

The last temperature graph, Figure 5.1.3-11, shows the temperatures of the target room door knobs. In Figure 5.1.3-11, the temperatures from single thermocouples, in contact with the outer surface of both the knob on the hall side of the door and the knob on the target room side of the door. The metal knob assembly was in working order and the knobs were connected by the "typical" metal rod which was also connected to the latch mechanism. The temperature of the knob on the hallway side of the door increased in temperature first as would be expected, reaching approximately 120 ºC (248 ºF) at the time that the window was vented. The temperature of the knob in the target room had not increased at that point in time. After the window vented, the hall knob temperature increased immediately, while the target room knob had a delay of approximately 30 s before it began to increase in temperature. After the door failed and burned away, at approximately 360 s after ignition, the thermocouples remained suspended in the doorway after the door knobs fell to the floor. Temperatures in the target room doorway increased to a peak of approximately 1200 ºC (2193 ºF) just prior to suppression.

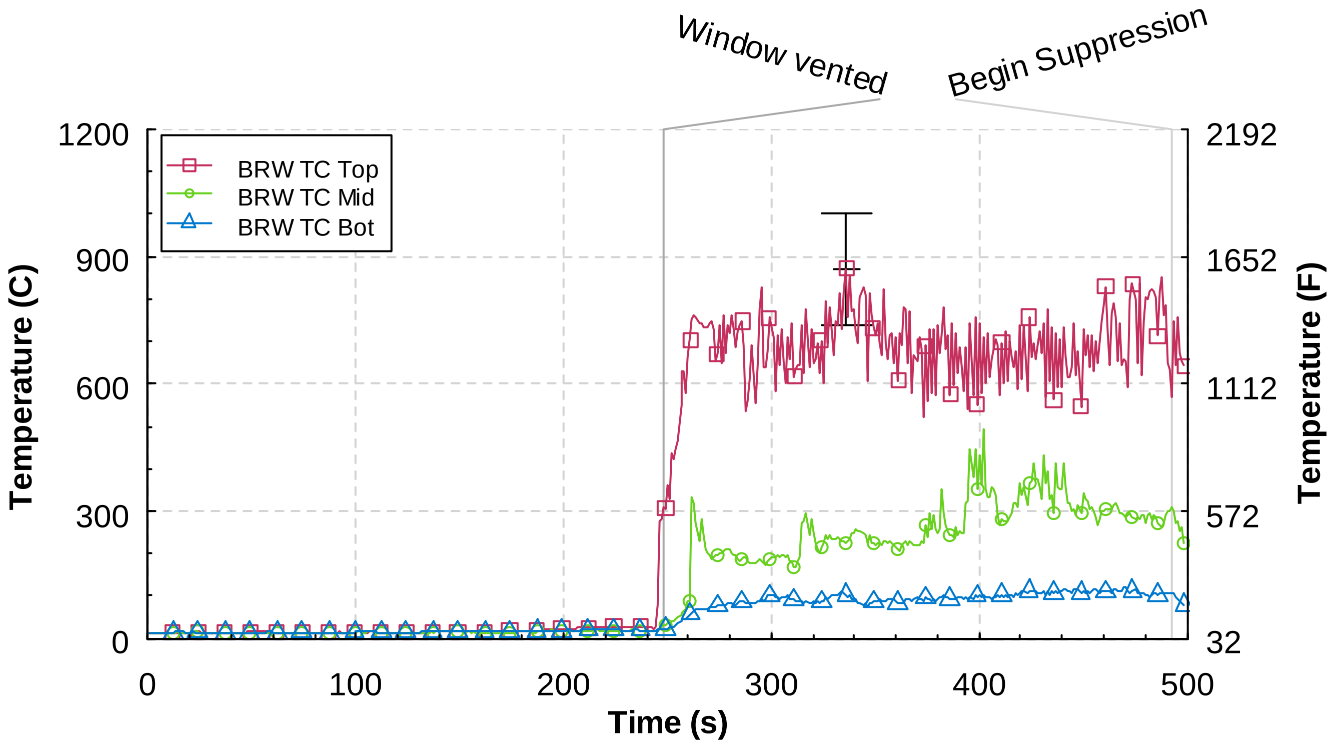

Figure 5.1.3-1. Temperature versus time from the bedroom window (BRW) thermocouple array, Experiment 1.

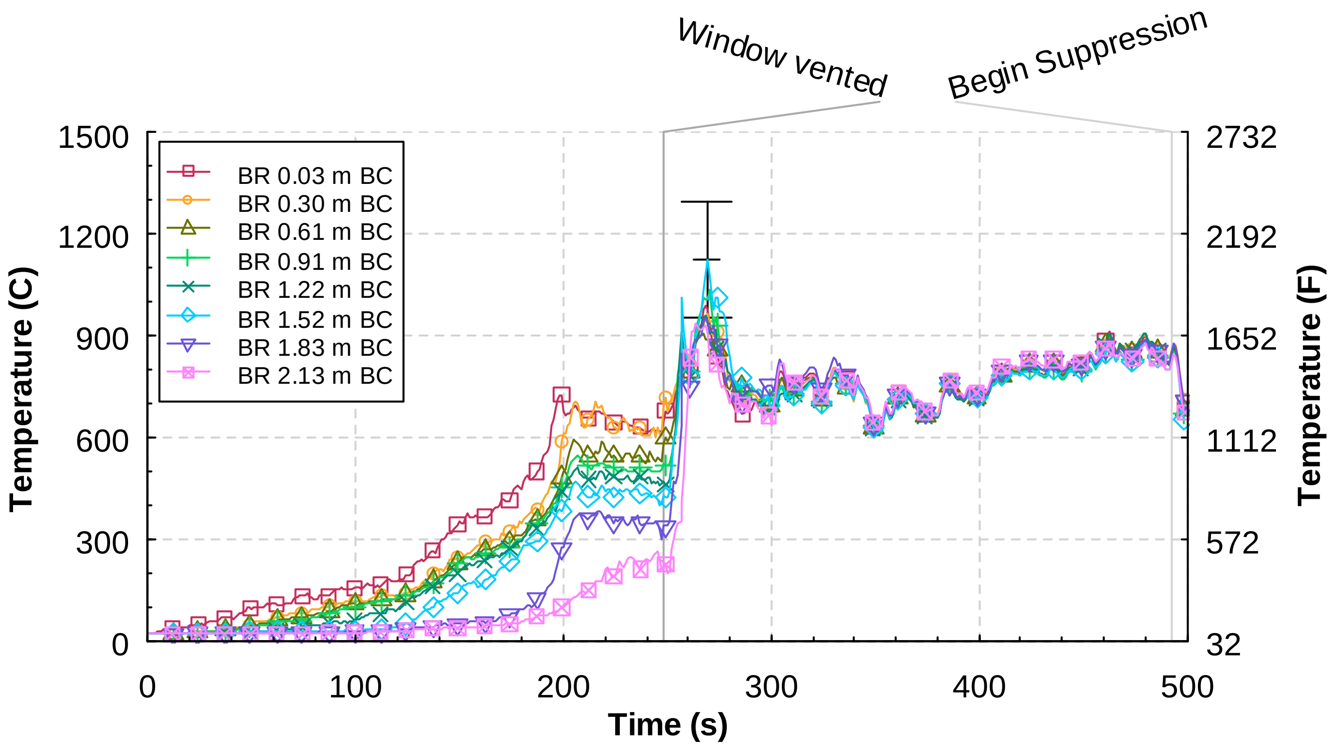

Figure 5.1.3-2. Temperature versus time from the bedroom (BR) thermocouple array, Experiment 1.

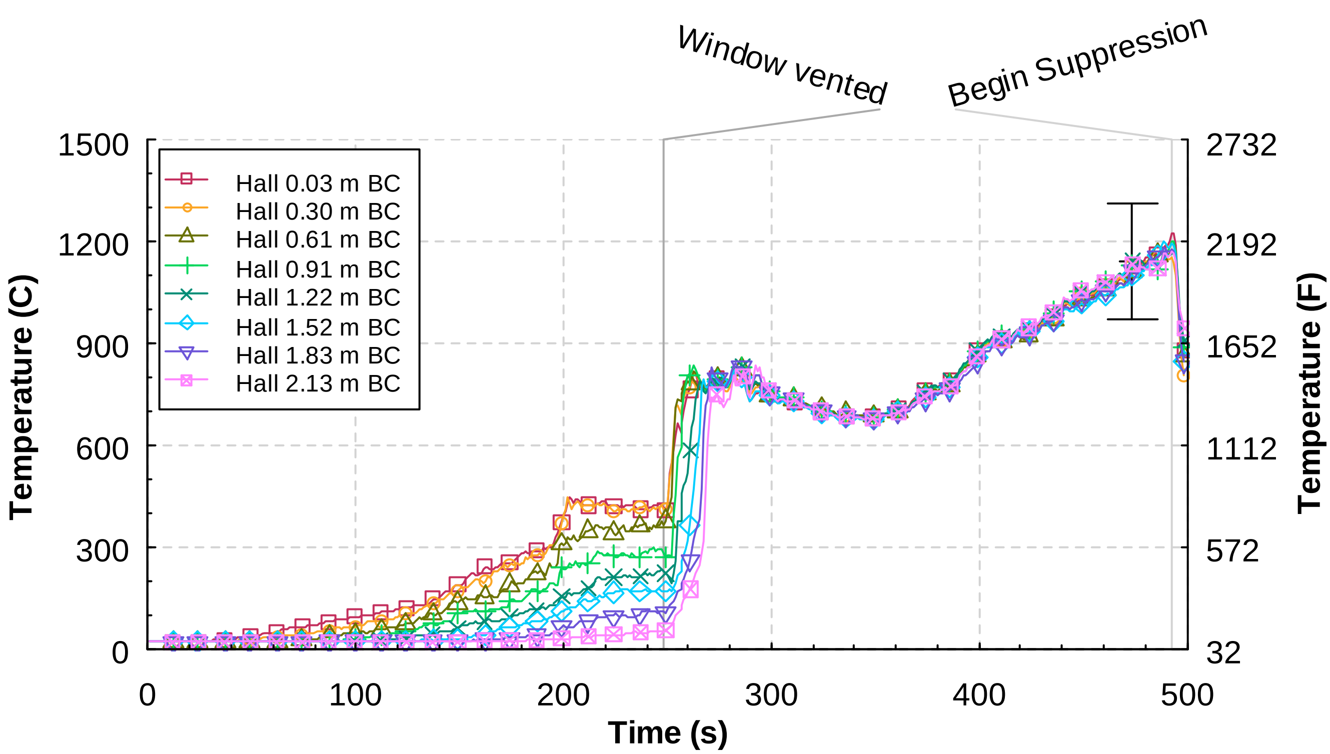

Figure 5.1.3-3. Temperature versus time from the hall thermocouple array, Experiment 1.

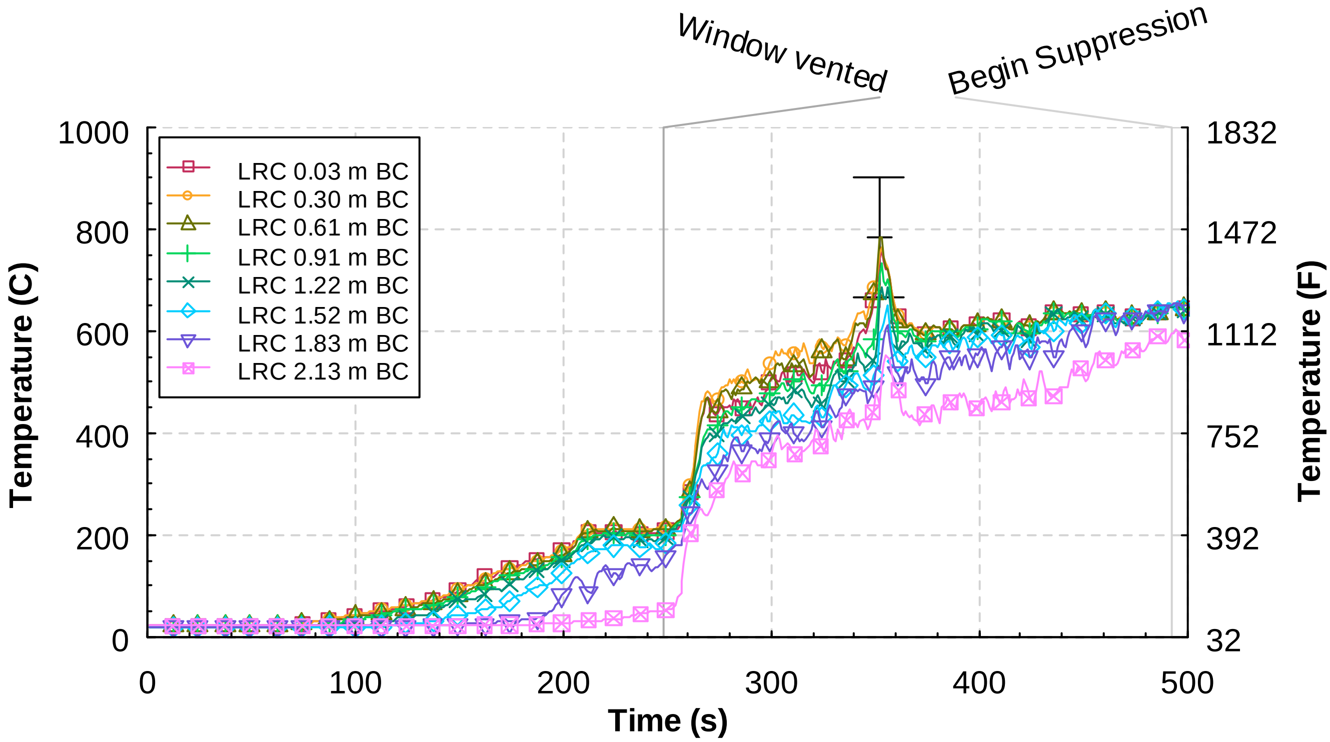

Figure 5.1.3-4. Temperature versus time from the living room corner (LRC) thermocouple array, Experiment 1.

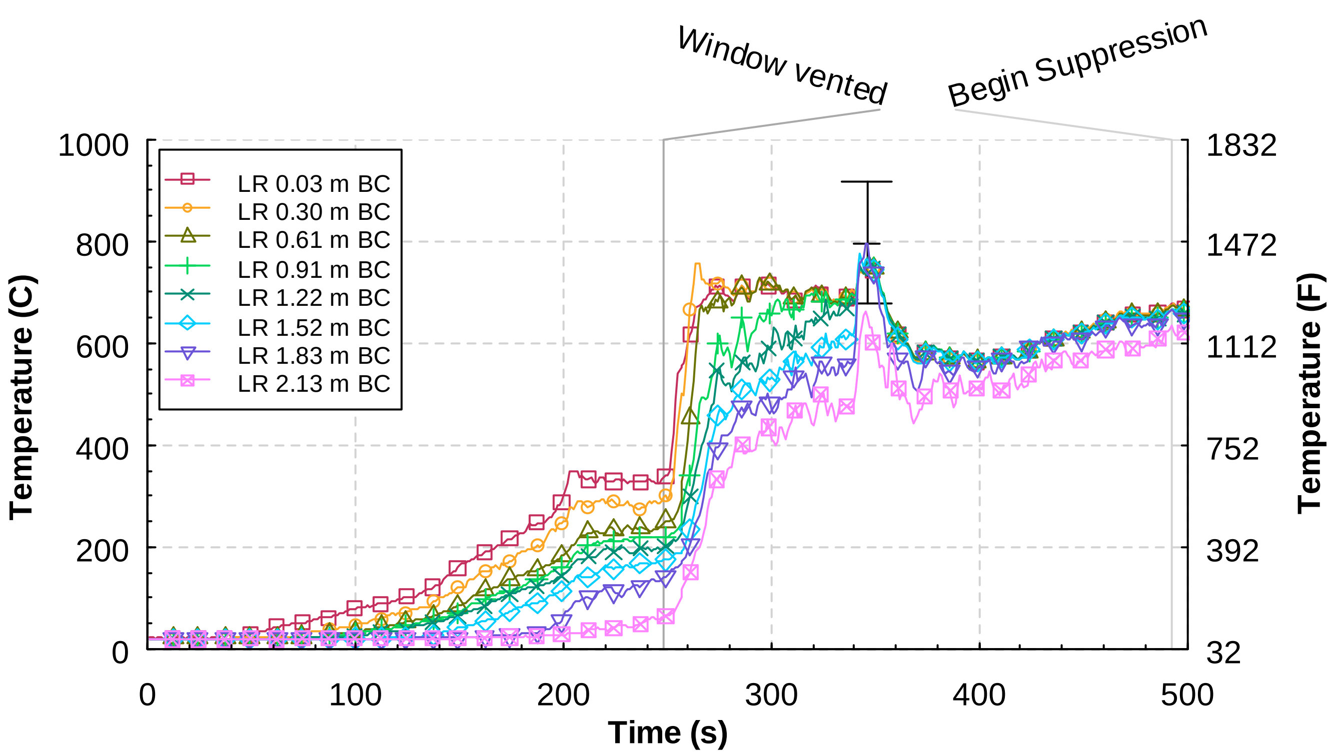

Figure 5.1.3-5. Temperature versus time from the living room (LR) thermocouple array, Experiment 1.

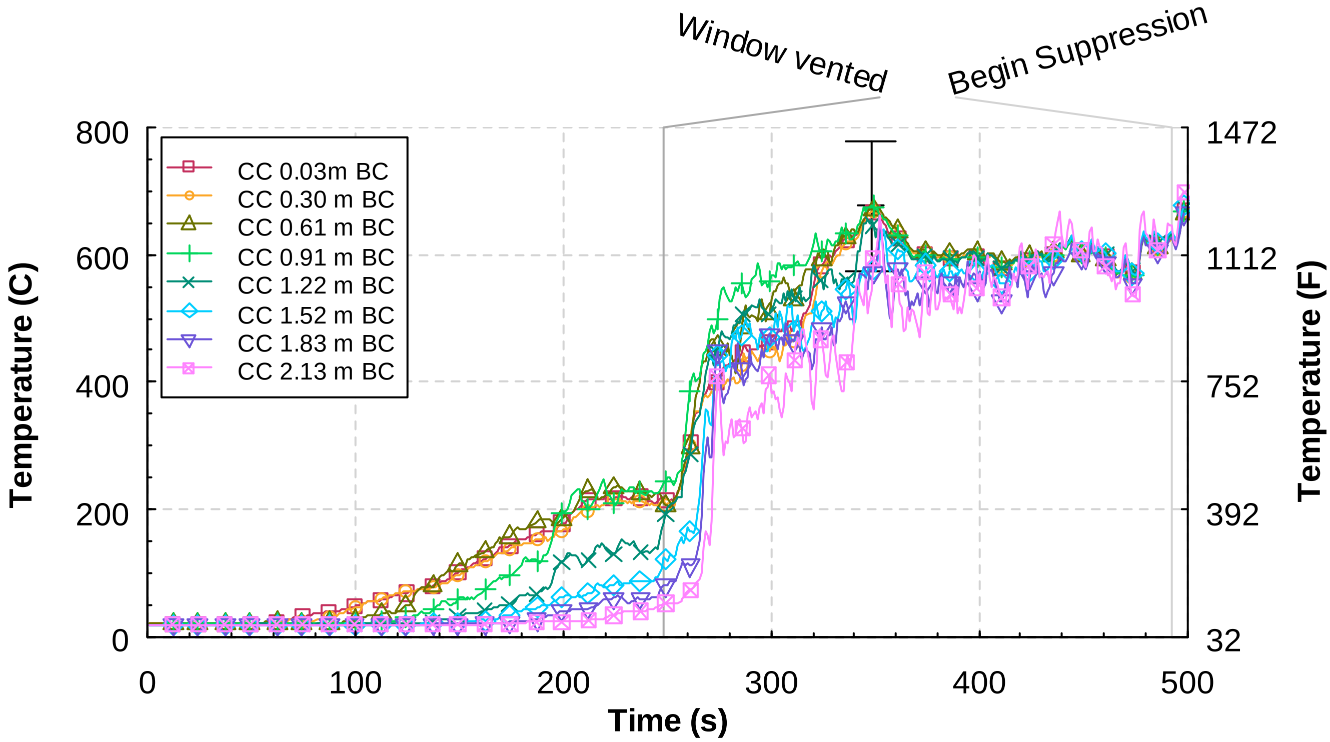

Figure 5.1.3-6. Temperature versus time from the corridor center (CC) thermocouple array, Experiment 1.

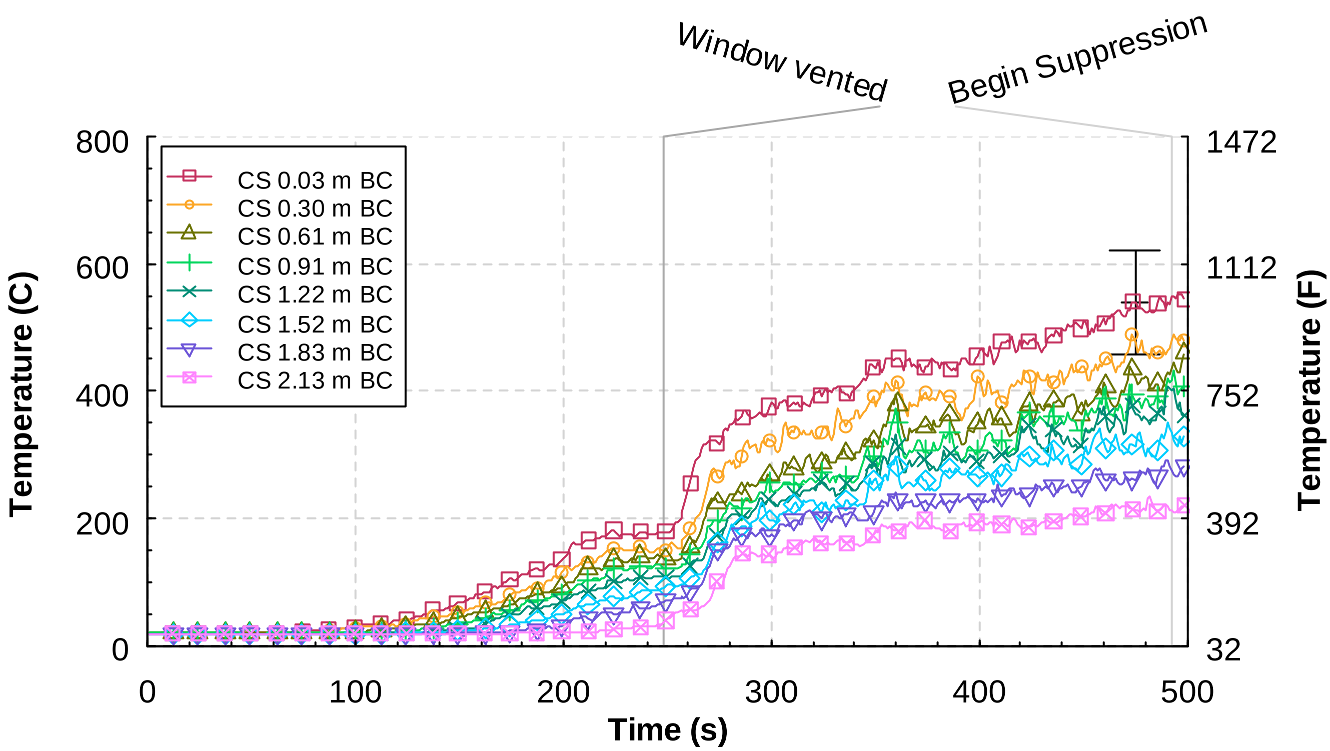

Figure 5.1.3-7. Temperature versus time from the corridor south (CS) thermocouple array, Experiment 1.

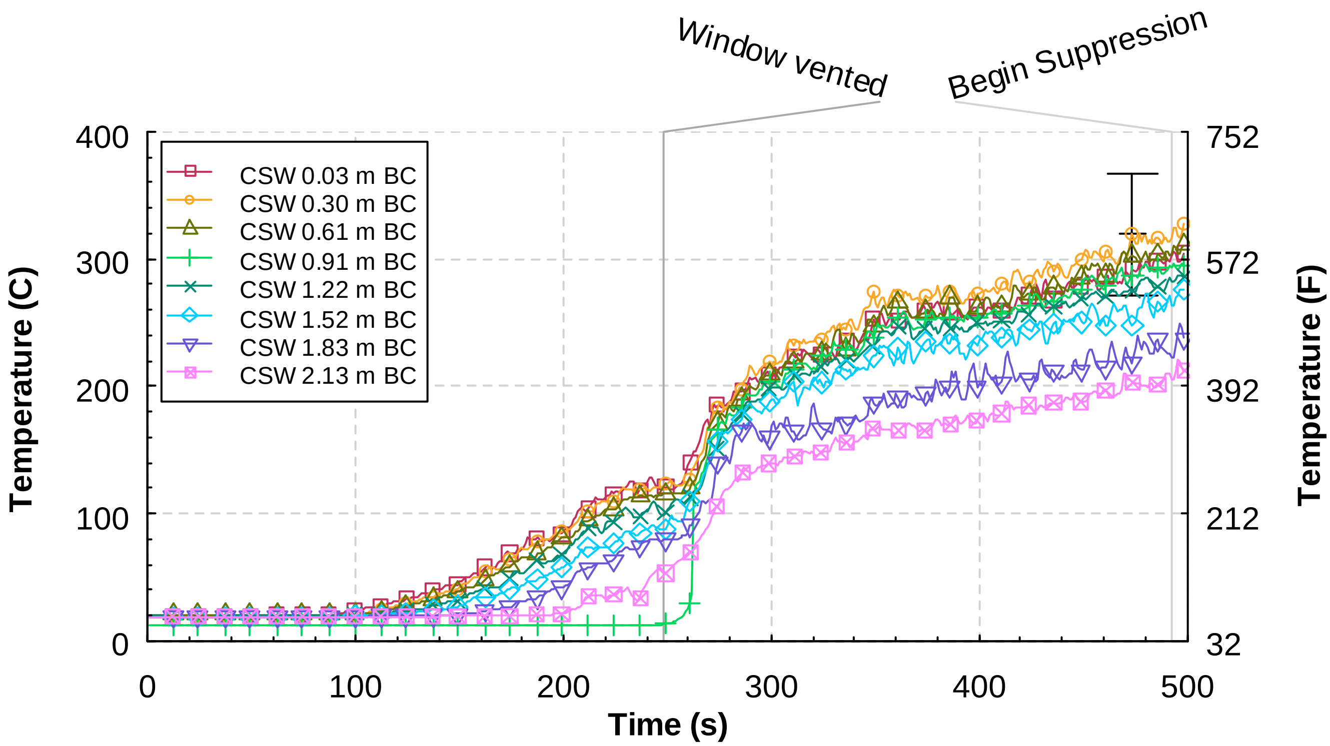

Figure 5.1.3-8. Temperature versus time from the corridor southwest (CSW) thermocouple array, Experiment 1.

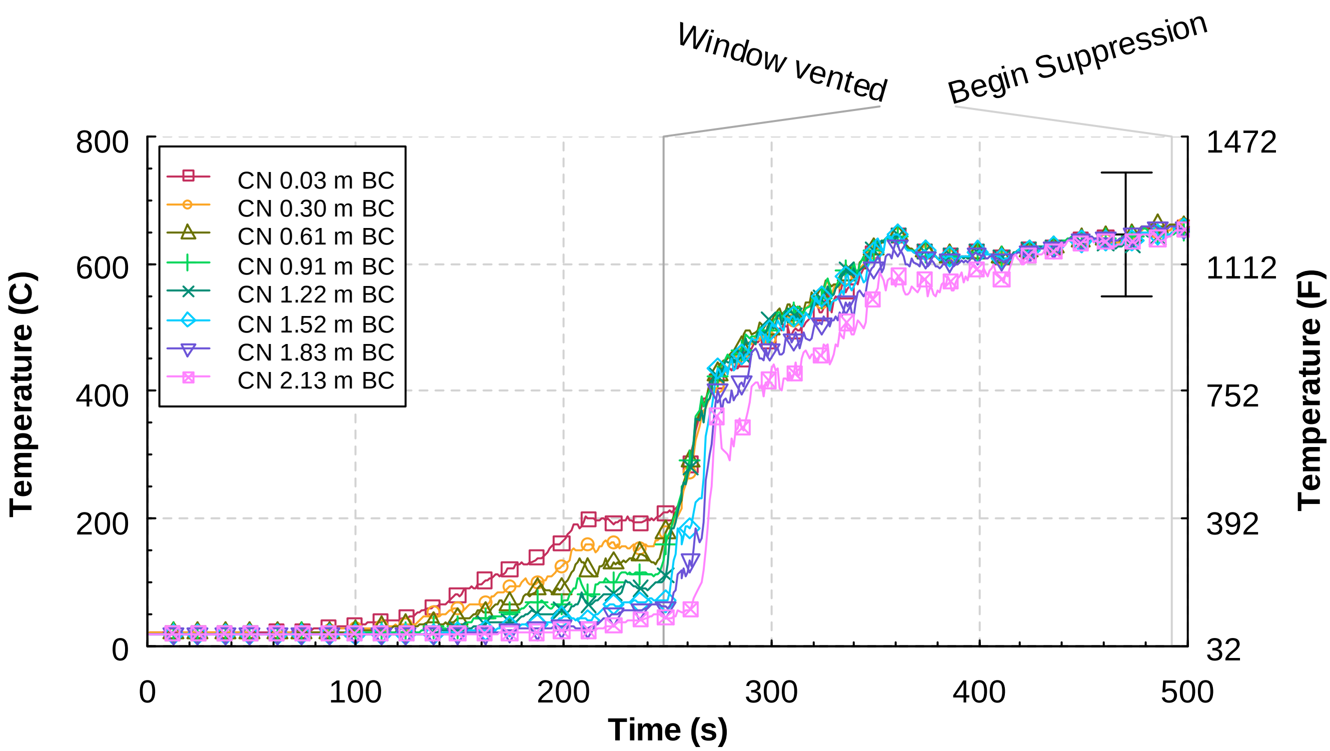

Figure 5.1.3-9. Temperature versus time from the corridor north (CN) thermocouple array, Experiment 1.

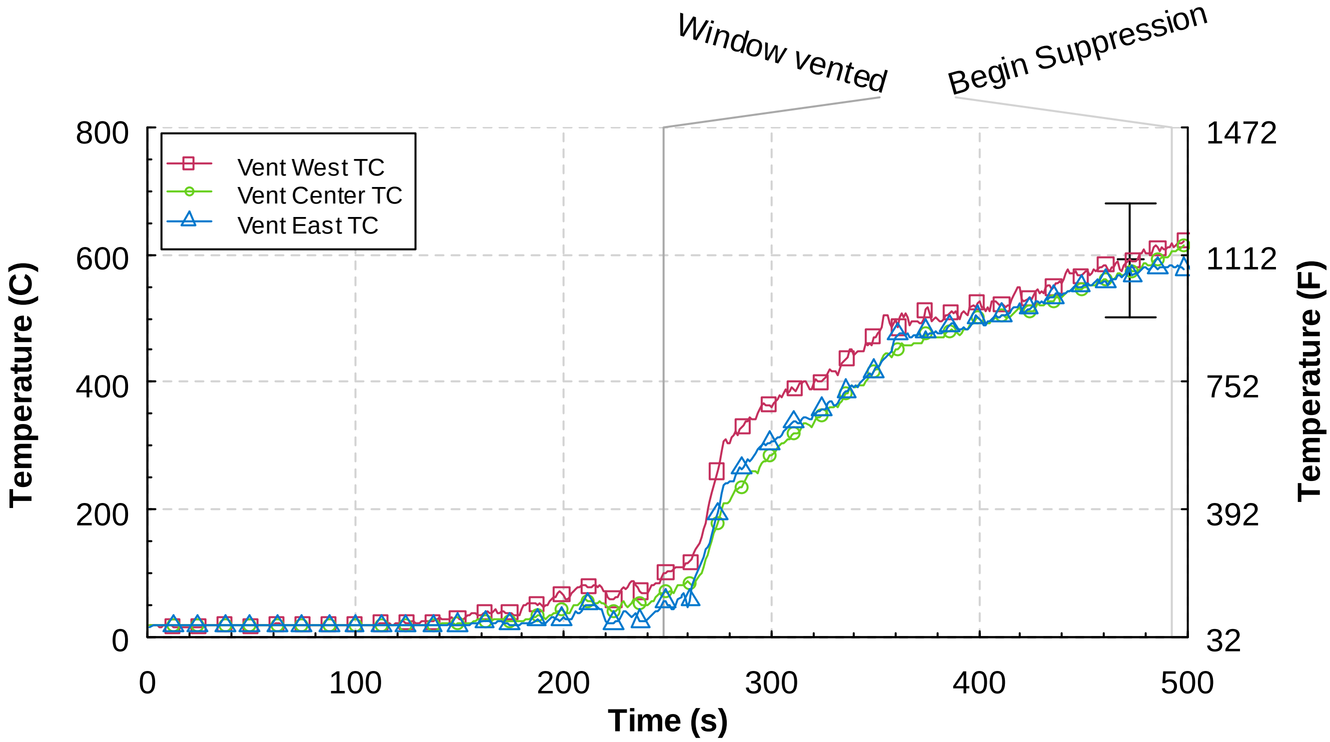

Figure 5.1.3-10. Temperature versus time from the ceiling vent thermocouple array, Experiment 1.

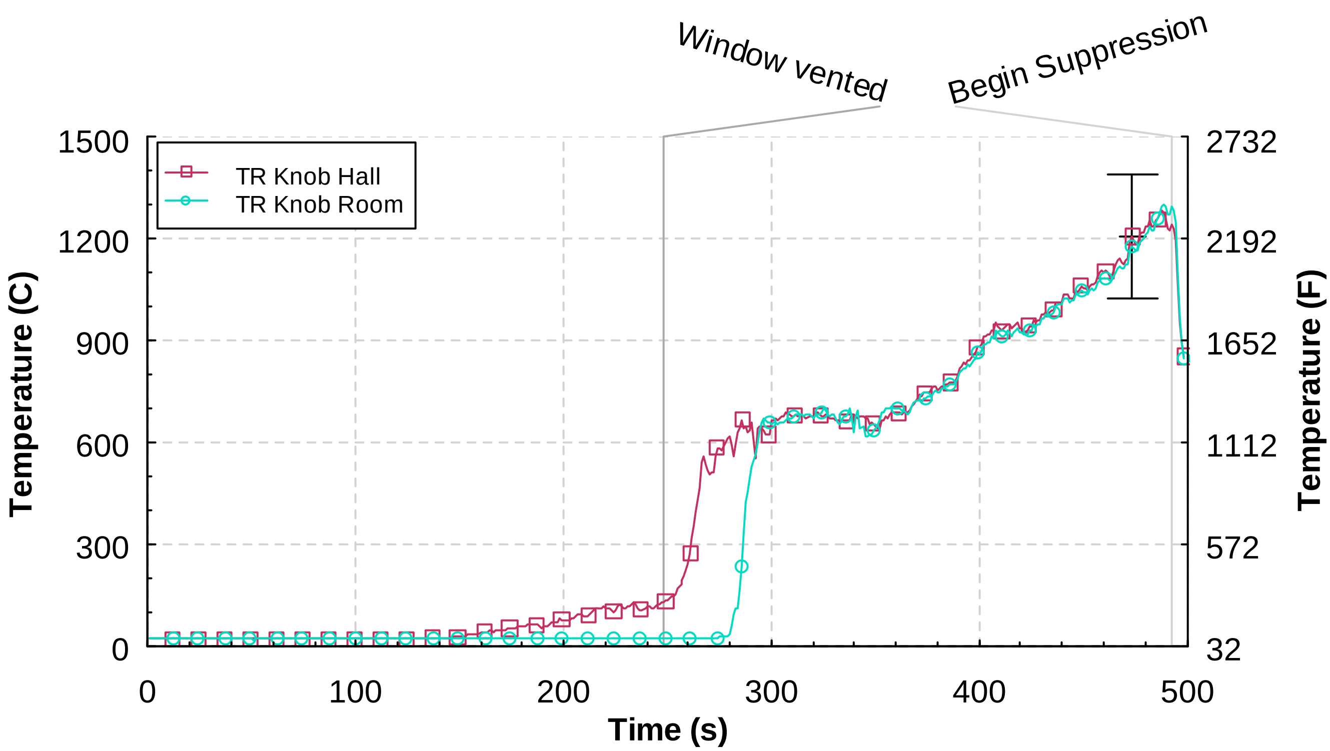

Figure 5.1.3-11. Temperature versus time from the target room (TR) door knobs, Experiment 1.

5.1.4 Heat Flux

The heat flux gauges were installed at five different locations in the experimental structure, as shown in Figure 4.1.3-1. The gauges were positioned in the center of the south wall of the bed room and the living room and at the three positions; north, center, and south, along the east wall of the corridor. All of the heat flux gauges were installed 1.52 m (5 ft) below the ceiling, a position chosen to be representative of the height of a crawling firefighter's head.

The time history from all five heat flux gauges is given in Figure 5.1.4-1. The heat flux in the bedroom increased to almost 30 kW/m^2 prior to the window failure. After the window vented, the heat flux measurement in the bedroom doubled within 30 s.

The measured heat fluxes in the hall, the center position of the corridor and the north position of the corridor increased in a manner after the window vented. The heat flux measurement in the south corridor position remained at a lower value throughout the test. This is consistent with the temperature measurements from the same position, Figure 5.1.3-7.

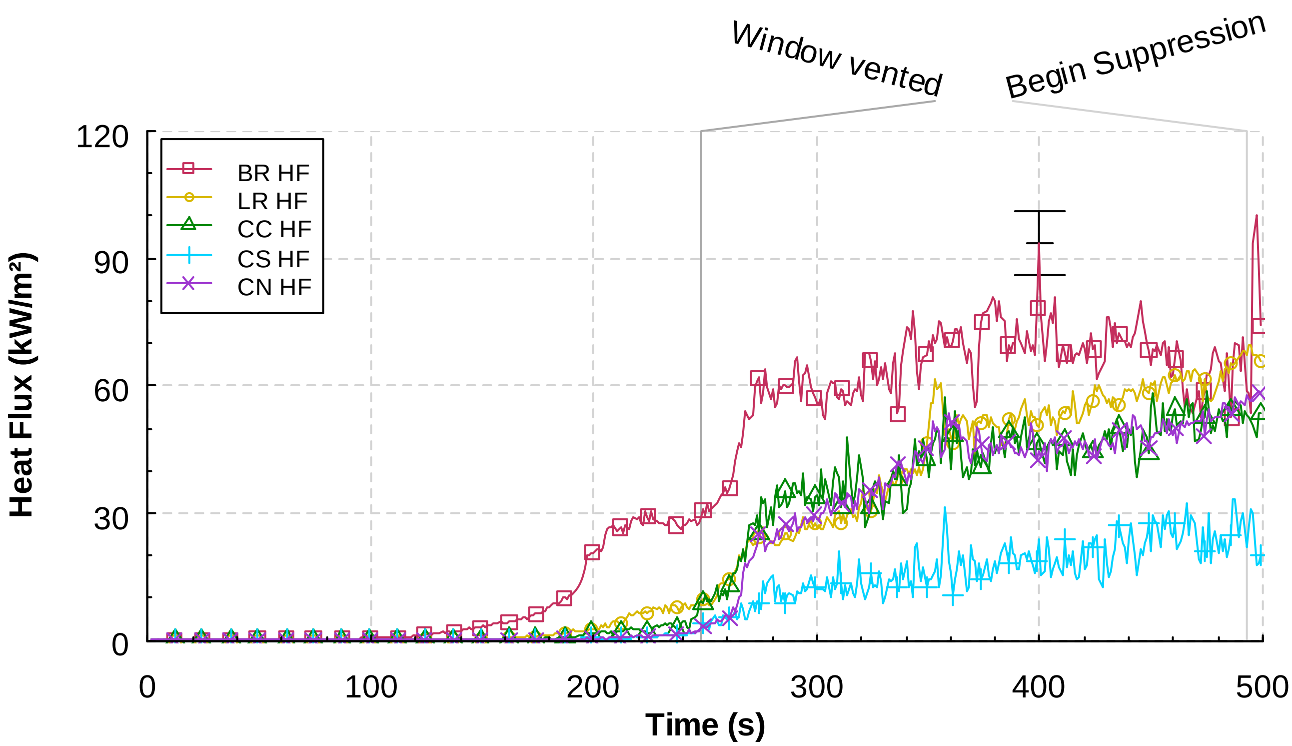

Figure 5.1.4-1. Heat flux versus time at five locations, Experiment 1.

5.1.5 Pressure

The differential pressure probes were installed at 1.22 m below the ceiling in the bedroom, hall, living room and in two positions in the corridor; northwest and southwest, as shown in Figure 4.1.3-1. All of the pressure readings began to go negative as the fire developed and began to exhaust hot gases out of the vent in the northwest ceiling of the corridor. As the window began to fail the pressure in the bedroom began to increase. After the window was completely vented, the pressure in the bedroom went positive for about 30 s, then it settled with values oscillating around 0 Pa differential pressure mark.

After the window vented, the other pressure readings displayed a brief period of pressure increase followed by a decrease which continued for the remainder of the experiment. As the flow path through the experimental structure was established, with a fraction of the combustion products exhausting and fresh air being entrained at the bedroom window and the remaining combustion products being exhausted from the northwest corridor ceiling vent, the pressure decreased, the closer the pressure probe was to the vent.

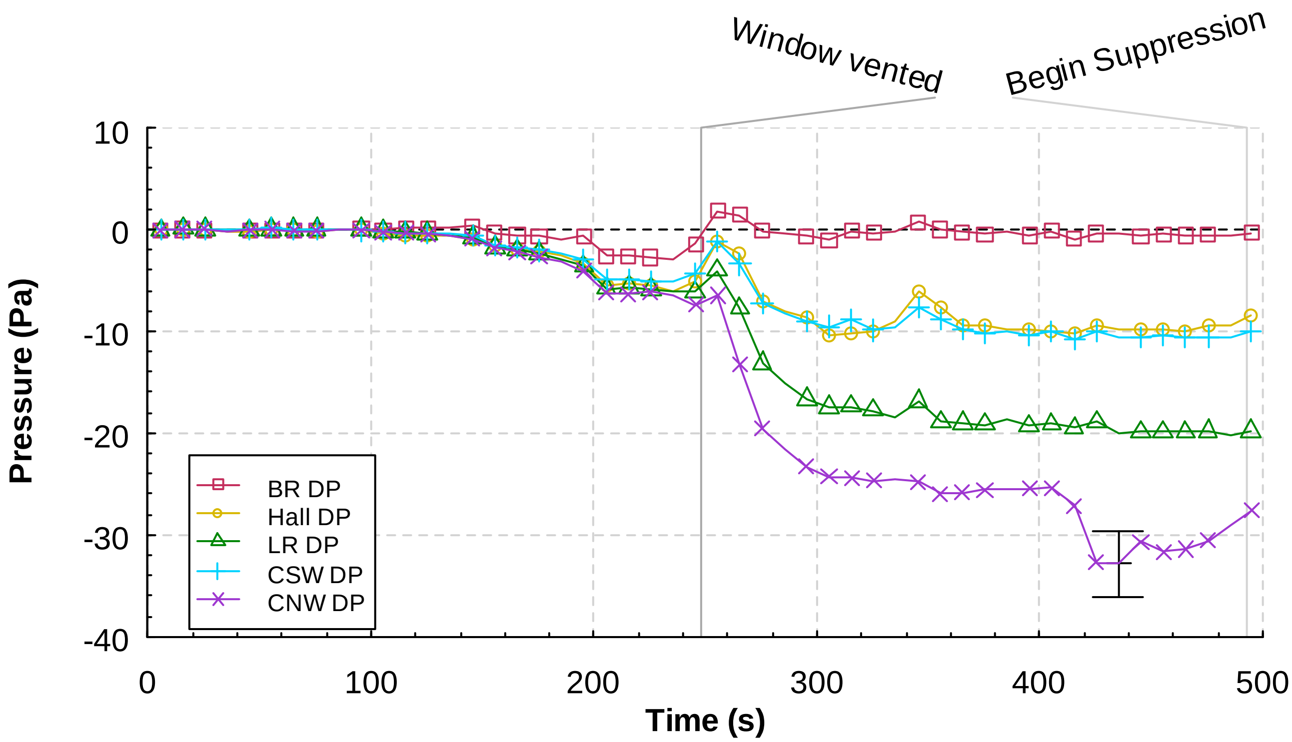

Figure 5.1.5-1. Pressure versus time at five locations, Experiment 1.

5.1.6 Velocities

Figure 5.1.6-1 through Figure 5.1.6-5 show the velocity measurements from the arrays of bi-directional probes located as shown in Figure 4.1.3-1. The velocities graphs are in order from west to east starting with the window position and ending with the bi-directional probes in the vertical vent in the northwest portion of the corridor.

Figure 5.1.6-1 provides the velocity measurements from the bi-directional probes that are located outside of the structure, 60 mm to the west of the window. These bi-directional probes are positioned at 0.38 m (1.25 ft), 0.76 m (2.50 ft) and 1.14 m (3.75 ft) below the top of the window opening, centered on north south axis, as shown in Figure 4.1.3-3. The back face of the probe was 60 mm (0.20 ft) in front of the window glass, as a result there is no measured velocity until after the window began to vent. The window was completely vented at 248 s after ignition as shown on the graph timeline. The combustion products venting out of the upper portion of the window has the positive velocity shown in the figure. Negative velocities are flowing in the window.

Figure 5.1.6-2 shows the velocities at the hall array position. On this graph, the positive direction is from west to east. The probe located 0.3 m (1 ft) below the ceiling captures the velocity of the ceiling jet as it moved down the hall away from the bedroom and peaked at approximately 3.0 m/s (6.7 mph).

Figure 5.1.6-3 displays the velocities from the south corridor position. The positive direction is from north to south. While the window was still intact, the velocity of the ceiling jet/hot gas layer reached a peak velocity of approximately 0.45 m/s (1.0 mph). After the window was vented, the ceiling jet/hot gas layer velocity increased to a of approximately 1 m/s (2.2 mph) at 0.3 m (1.0 ft) below the ceiling. The negative velocities at 2.13 m (7.0 ft) below the ceiling are indicative of the gases re-circulating from the closed end of the corridor. The low speeds are due to the higher pressure (less negative), relative to the north portion of the corridor.

The velocities from the north corridor position are shown in Figure 5.1.6-4. The positive flow direction for this location is from south to north. Prior to window failure, the ceiling jet/hot gas layer velocities reached a peak of approximately 0.6 m/s (1.4 mph) at 0.3 m (1 ft) below the ceiling. After the window vented the velocities increased to a peak of approximately 4 m/s (9 mph) prior to suppression, at 1.22 m (4.0 ft) below the ceiling. Since the measurement position was in the direct flow path between the living room and the ceiling vent in the northwest section of the corridor, the peak velocities were approximately four times higher than the velocities at the south corridor position and the flow from ceiling to floor was in the northern direction. The velocities measured at the bi-directional probes at 0.3 m (1.0 ft) below the ceiling and 2.13 m (7.0 ft) below the ceiling leveled off around the 3 m/s (6.7 mph) range for almost two minutes.

The measurements from the bi-directional probes installed in the exhaust vent, 2.44 m (8.0 ft) above the ceiling are given in Figure 5.1.6-5. The probes are spaced 0.51 m (1.67 ft) apart along the east-west centerline of the vent. The flow direction up and out of the structure is positive in the figure. Prior to the window being vented the peak flow velocity is less than 1 m/s (2.2 mph) at the east probe, while it appears that slight downdrafts maybe coming in on the west side of the vent for make-up air. After the window was vented, the velocities at all three probes are similar and in the same direction, flowing out of the structure. The average peak velocity of the three probes is approximately 5.5 m/s (12.1 mph) out of the exhaust vent just prior to suppression.

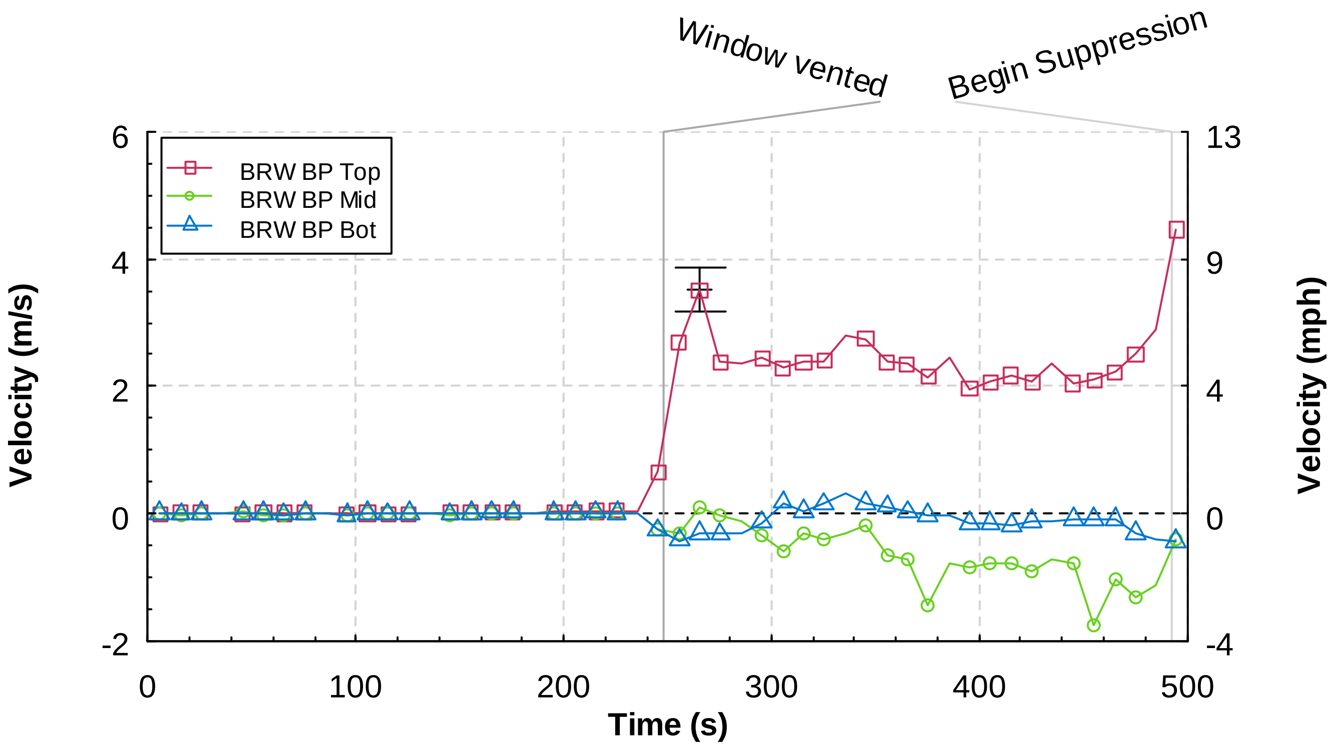

Figure 5.1.6-1. Velocity versus time from the bedroom window (BRW) bi-directional probe array, Experiment 1.

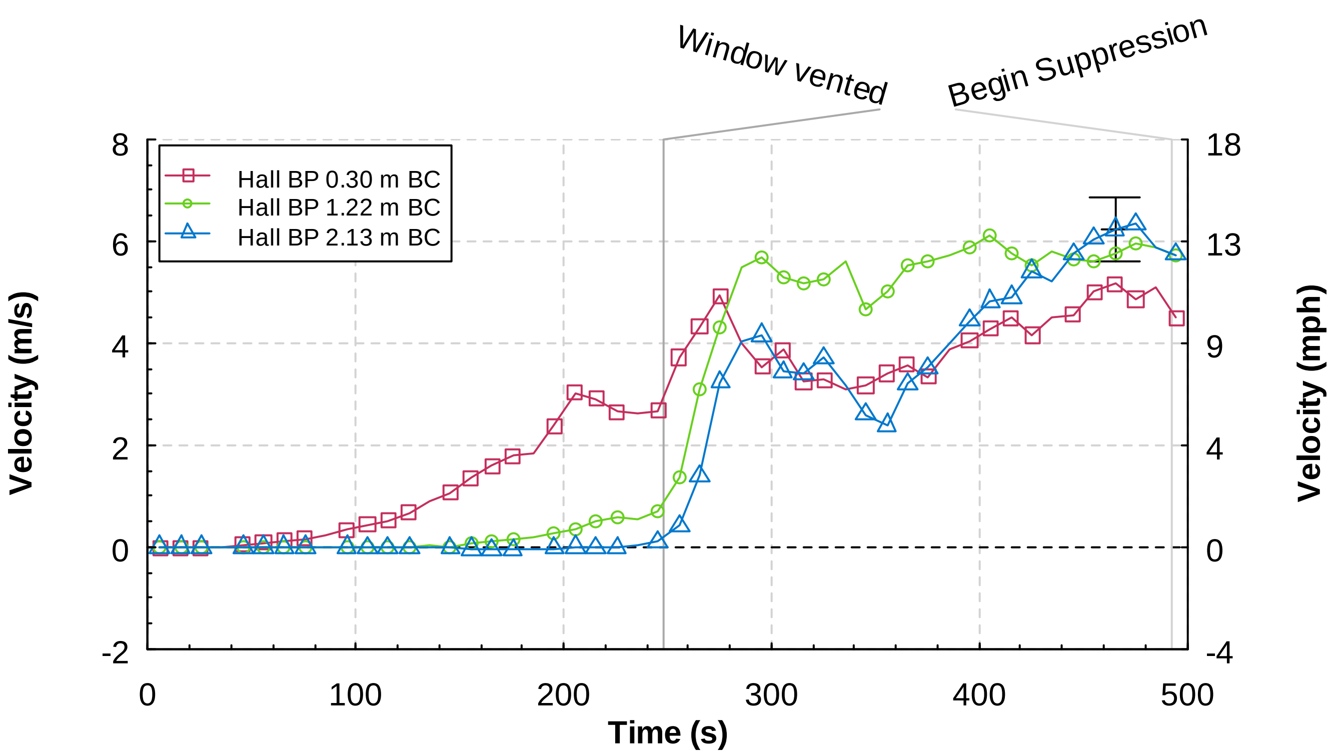

Figure 5.1.6-2. Velocity versus time from the hall bi-directional probe array, Experiment 1.

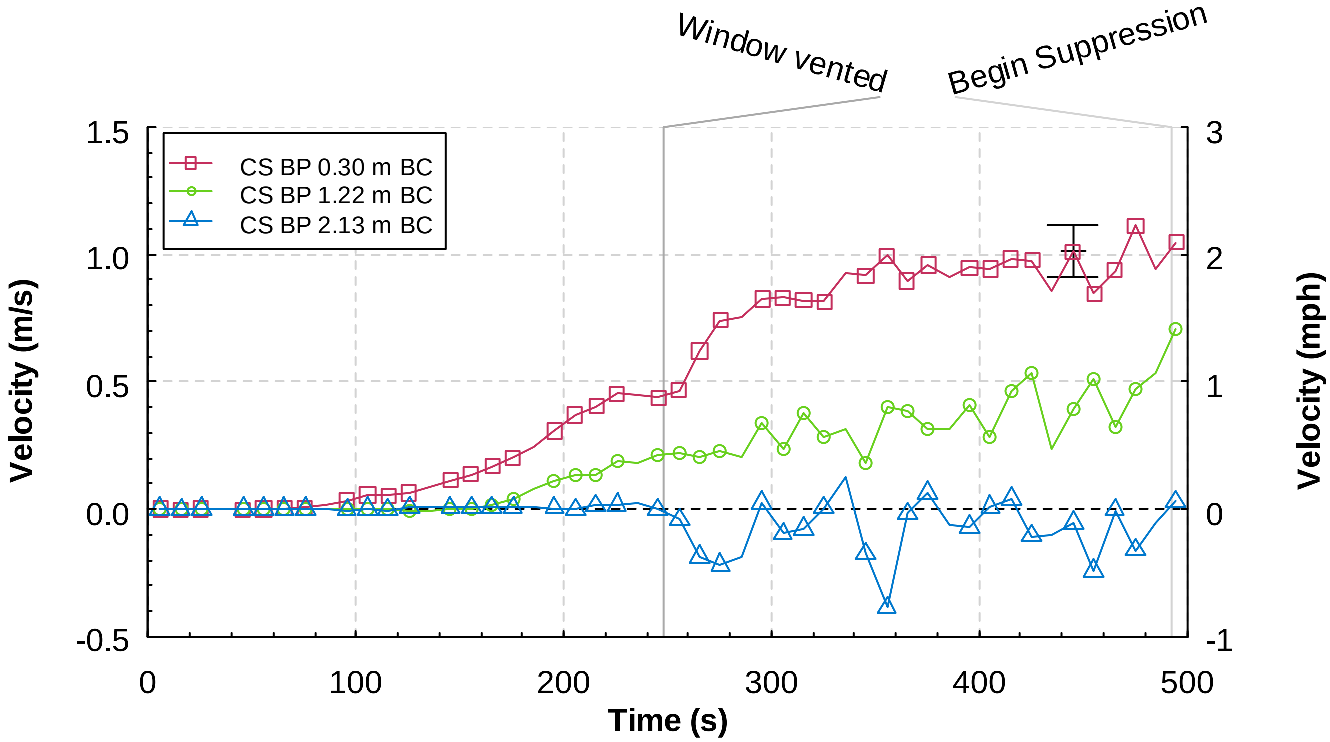

Figure 5.1.6-3. Velocity versus time from the corridor south (CS) bi-directional probe array, Experiment 1.

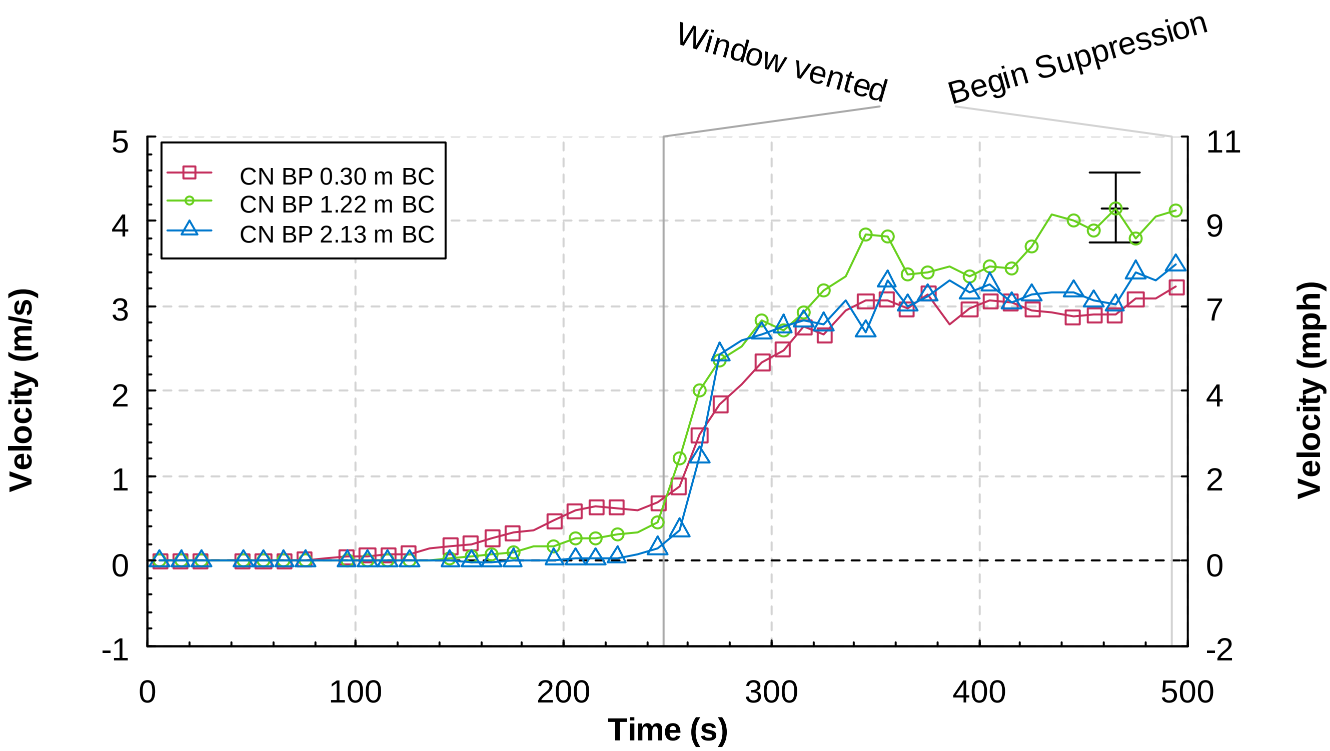

Figure 5.1.6-4. Velocity versus time from the corridor north (CN) bi-directional probe array, Experiment 1.

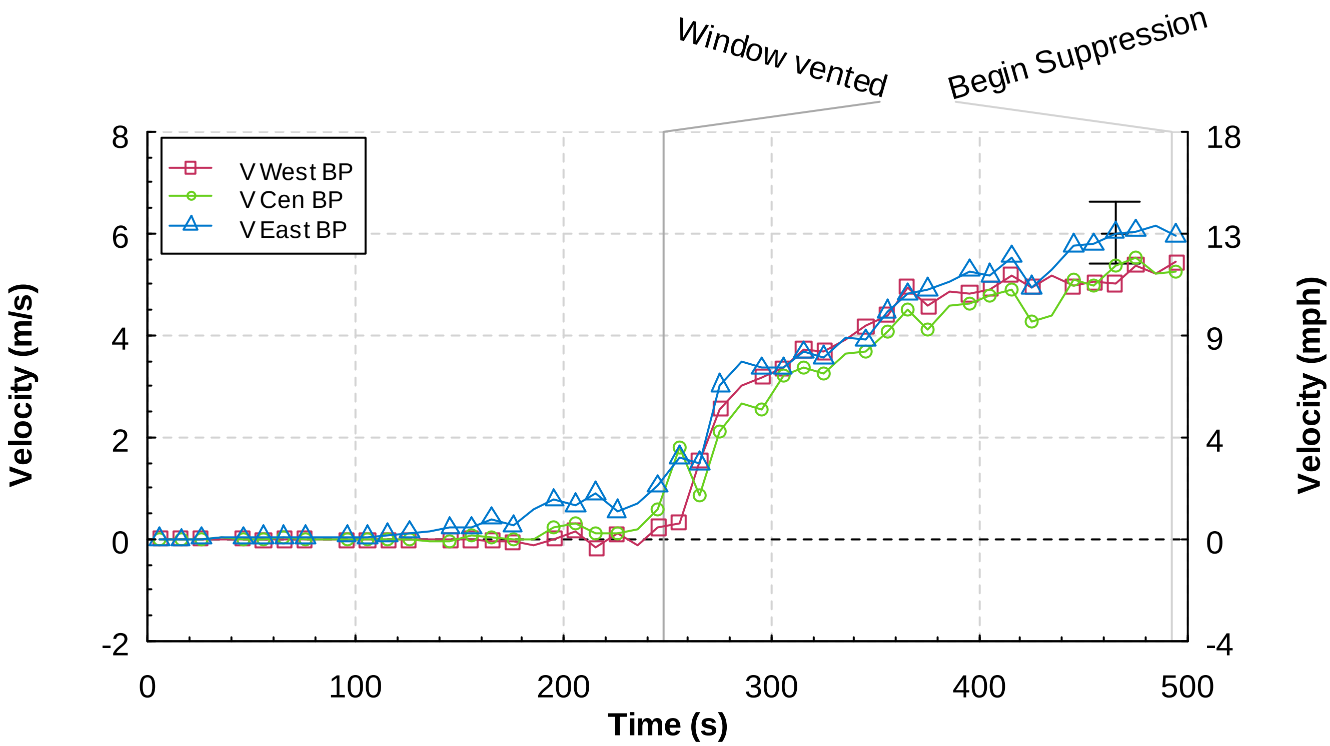

Figure 5.1.6-5. Velocity versus time from the ceiling vent (V) bi-directional probe array, Experiment 1.

5.1.7 Gas Concentrations

Measurements were made to determine the concentrations of oxygen, carbon dioxide, carbon monoxide and in some cases total hydrocarbons. Since ventilation is such a major factor in structure fires, these measurements were intended to provide insight as to the availability of oxygen and the resulting combustion products in the bedroom and living room areas.

Two gas sampling probes were used in each room. The gas sampling points are located in the center of the south wall of both rooms, 0.91 m (3 ft) north of the south wall and at positions 0.61 m (2 ft) and 1.83 m (6 ft) below the ceiling. These positions are shown in Figure 4.1.3-1. In this experiment, total hydrocarbon measurements were made at the upper layer positions in the bedroom and the living room.

Figure 5.1.7-1 and Figure 5.1.7-2 show the gas concentration measurements made in the bedroom. At the start of the experiment, the oxygen is approximately 21 % and the combustion products are near zero. As the fire grew, the oxygen in the upper layer, Figure 5.1.7-1, slowly decreased to approximately 19 % within 180 s after ignition. During the same period, the carbon dioxide increased noticeably. After 180 s after ignition the rate of oxygen depletion increased and the generation rate of carbon dioxide, carbon monoxide and total hydrocarbons increased. These trends continued and did not level off until approximately 330 s after ignition.

The gas concentrations in the lower portion of the room began to change later in the experiment, as the hot gas layer had to develop and extend down 1.83 m (6.0 ft) from the ceiling to interact with the sampling probe. Once the hot gas layer descended to the location of the lower probe, approximately 180 s, the rates of change of the gas concentrations were more rapid than in the upper layer because the fire was more developed at this point. After the window vented, the fresh air came in through the window and mixed with the lower portion of the hot gas layer, which significantly reduced the amount of carbon dioxide and carbon monoxide and increased the amount of oxygen.

Figure 5.1.7-3 and Figure 5.1.7-4 provide the measurements from the upper and lower gas sampling probes, respectively, in the living room. The trends from the upper probe are very similar to those from the upper probe in the bedroom. The oxygen depletion and combustion product generation rates lag in time, relative to the bedroom by at least 30 s. After the window vented, the end points for the oxygen, approximately 0, and carbon monoxide, approximately 18 % are similar for both the bedroom and the living room. At 350 s after ignition, the carbon monoxide and the total hydrocarbons in the living room have significantly higher peak values, approximately 7 % and 11 % respectively, than those of the bedroom, which were both approximately 4 % at that time. Just prior to suppression, these values in the bedroom increased and they decreased in the living room such that they were all between 5.5 % and 7 %.

Figure 5.1.7-4 shows the measured gas concentrations from the lower probe in the living room. Compared to the readings from the lower probe in the bedroom, the initial change from ambient conditions occurred at about the same time, approximately 180 s, however the rate of change was significantly slower in the living room. After the window vented the rate of change increased. Oxygen decreased to near 0 % within 80 s after the window was vented and carbon dioxide had increased to approximately 17 % and carbon monoxide had increased to approximately 7 % at about the same time. The oxygen level stayed at 0 for the remainder of the experiment, which indicted that no fresh air was reaching the probe. The carbon dioxide and carbon monoxide reading remained elevated.

Figure 5.1.7-5 is a comparison graph of the total hydrocarbon readings from the upper gas sampling probes in the bedroom and the living room. Post-window venting, the total hydrocarbon readings in the upper layers increase, although the measurements from the living room more than double the readings in bedroom where fresh air is being entrained through the window. Given the lack of oxygen in the living room, based on the previous figures, no combustion is occurring in the living room, hence the high levels of carbon dioxide, carbon monoxide, and total hydrocarbons. This graph is a good example of the "smoke is fuel" concept.

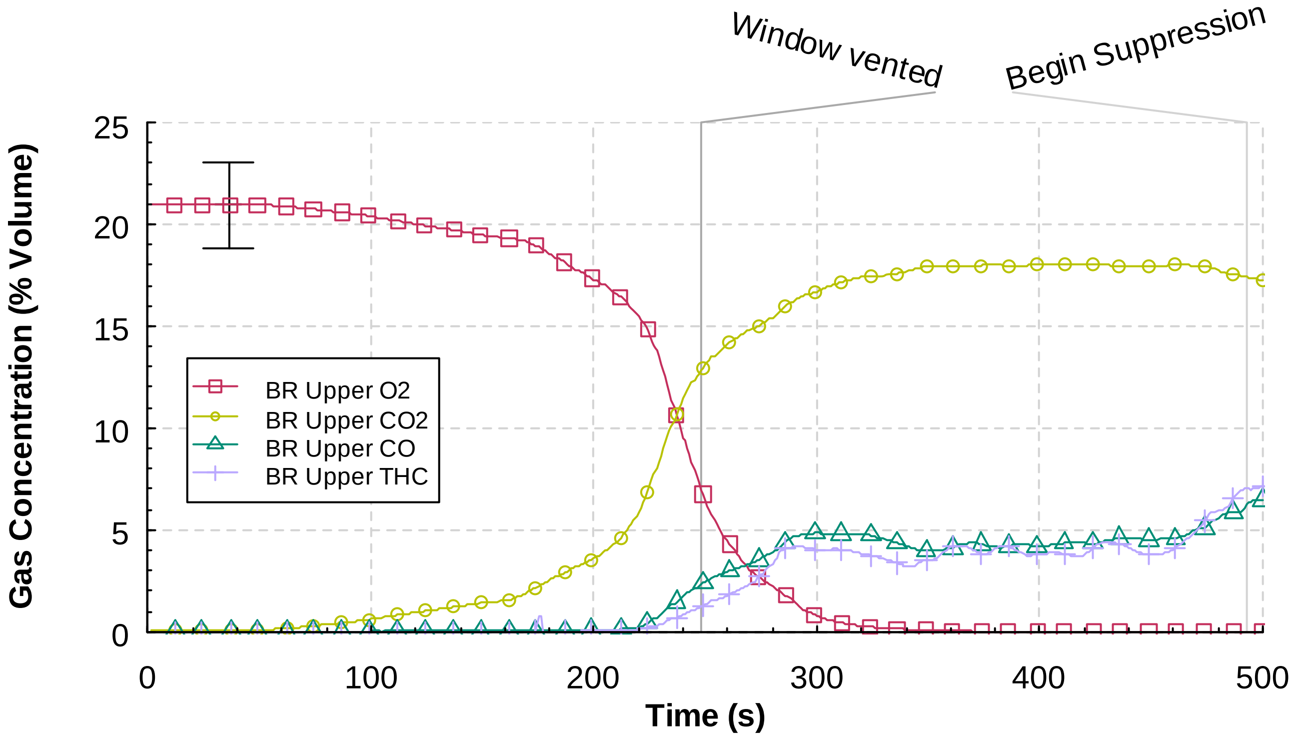

Figure 5.1.7-1. Oxygen, carbon dioxide, carbon monoxide, and total hydrocarbon percent volume versus time from the upper bedroom (BR) sampling location, Experiment 1.

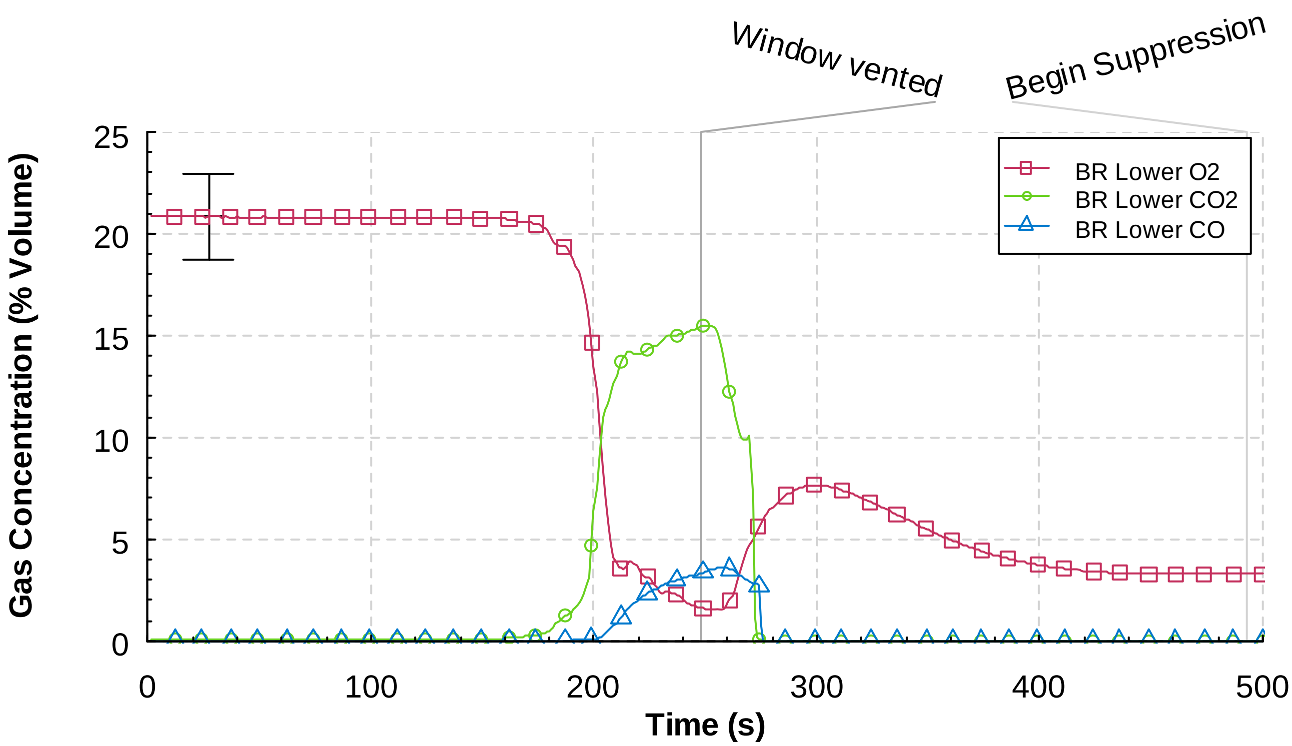

Figure 5.1.7-2. Oxygen, carbon dioxide, and carbon monoxide percent volume versus time from the lower bedroom (BR) sampling location, Experiment 1.

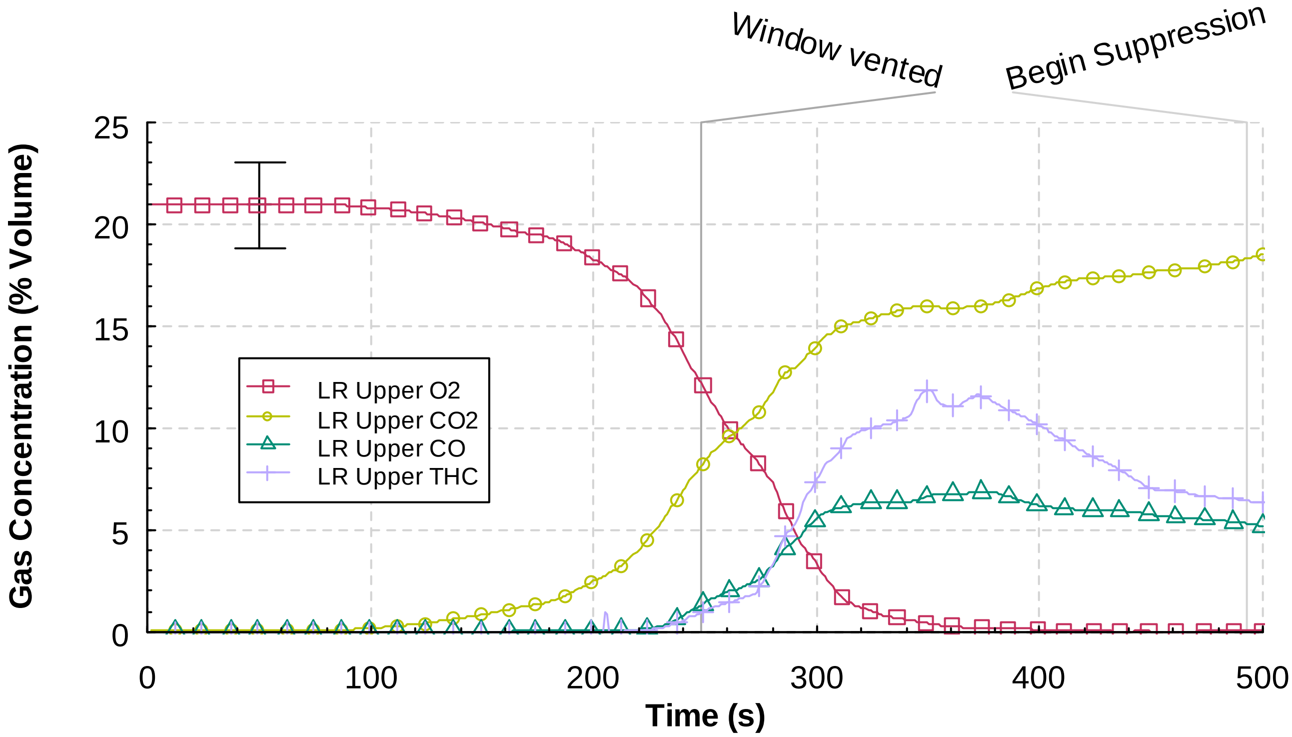

Figure 5.1.7-3. Oxygen, carbon dioxide, carbon monoxide, and total hydrocarbon percent volume versus time from the upper living (LR) room sampling location, Experiment 1.

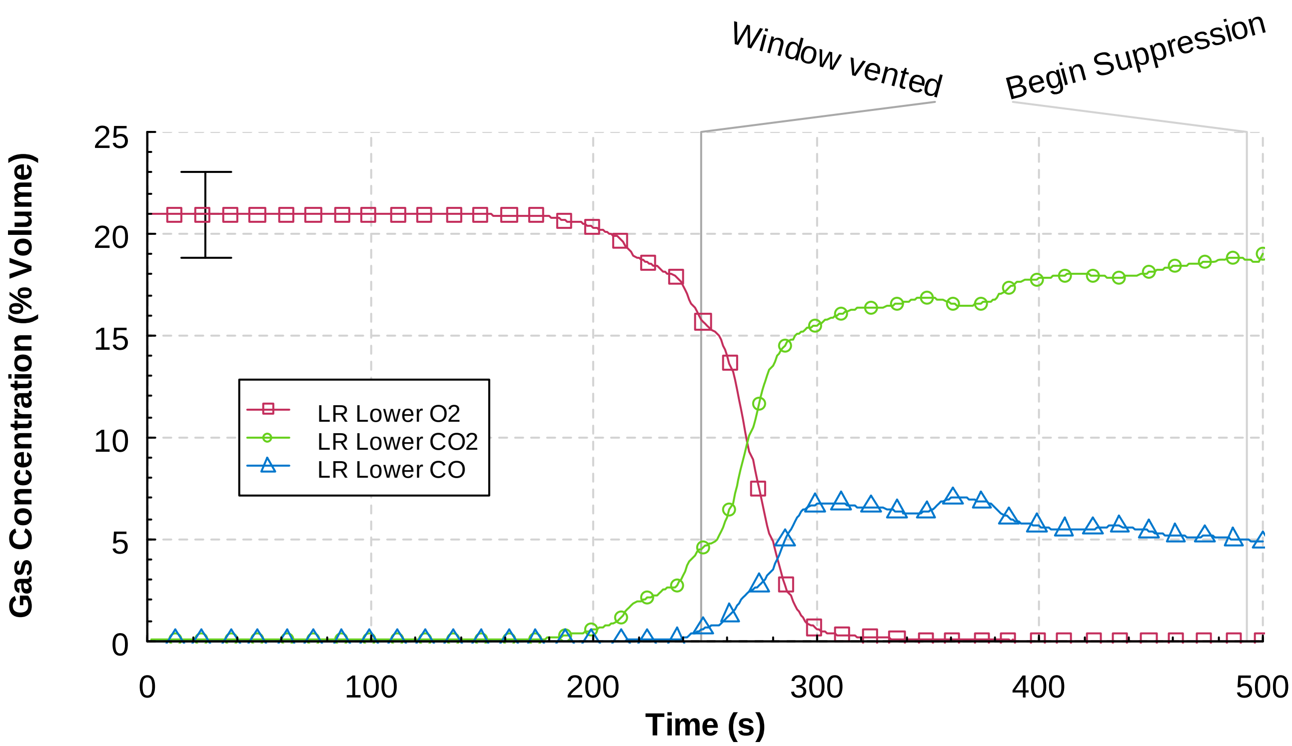

Figure 5.1.7-4. Oxygen, carbon dioxide, and carbon monoxide percent volume versus time from the lower living room (LR) sampling location, Experiment 1.

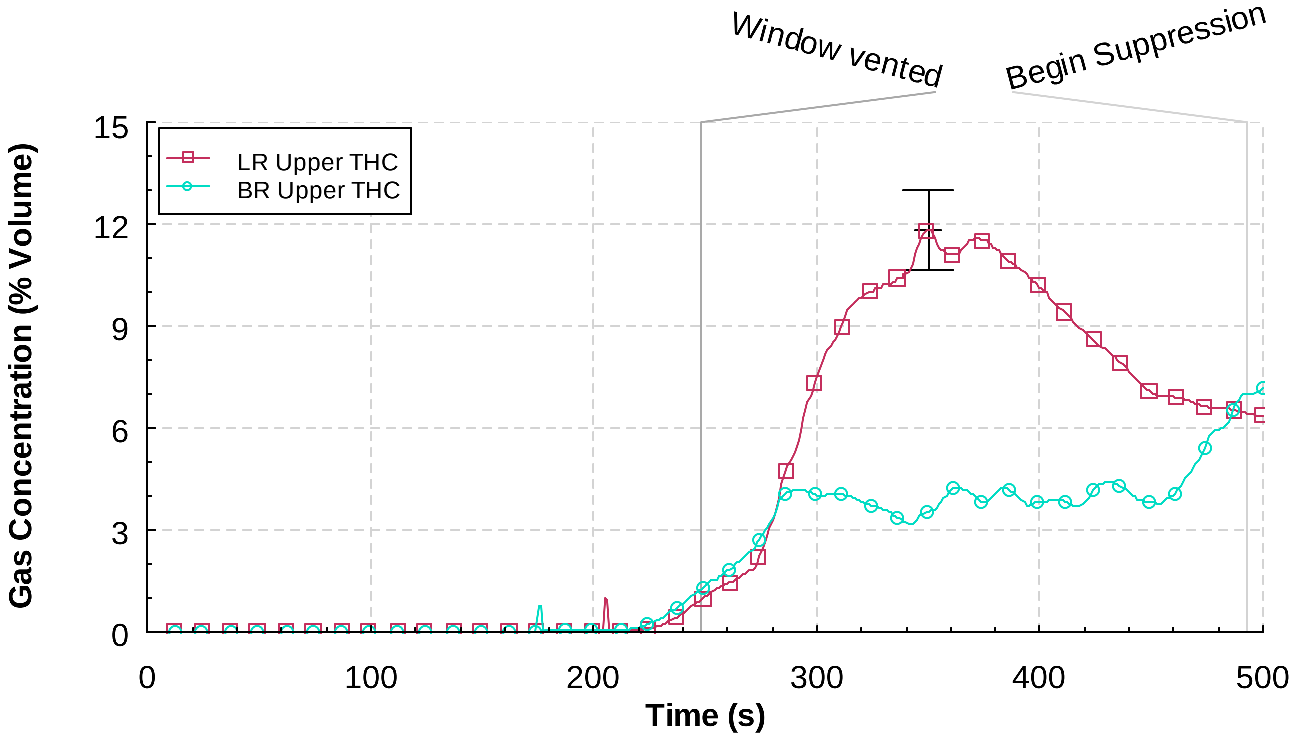

Figure 5.1.7-5. Total hydrocarbon percent volumes versus time from the upper bedroom (BR) and living room (LR) sampling locations, Experiment 1.

5.2 Wind Control Devices WDF 2

The second experiment in the series was conducted to examine the impact of wind on the structure fire and quantify the impact of the large wind control device. The large wind control device measured 2.95 m (9.66 ft) by 3.66 m (12.0 ft). In the wind control experiments, as described in Section 4.3.2, the wind control device reduced the velocity in the structure to zero. The experimental preparations were made as described in Section 4. The fan speed used in this experiment was 2500 RPM, which provided a 6.7 m/s to 8.9 m/s (15 mph to 20 mph) wind speed at the window opening. A trash container fuel package was ignited remotely with and electric match to start the experiment at Time = 0 s. A time line of the experiment is presented in Table 5.2-1. The results for the experiment are presented in the following sections: observations, heat release rate, temperature, heat flux, pressure, velocity, and gas concentrations. An uncertainty range marker is included in each graph.

Table 5.2-1. Experiment 2 Timeline

Time (s)	Event
0	Ignition
50	Visible smoke layer
167	Window vented mostly
169	Hot gas flow to floor in corridor IR
180	Window completely vented (bottom cleared)
201	WCD on
255	WCD part off
271	WCD off
293	Begin suppression

5.2.1 Observations

The observations are presented as a series of images captured from eight camera locations, six were video cameras and two were thermal imaging cameras. The camera positions are shown in Figure 4.1.3-1.

Figure 5.2.1-1 through Figure 5.1.1-11 present sets of eight images one from each camera position, at a given time, from the time of ignition to 300 s after ignition. Each image view is labeled. The first four views at the top of each figure show the west wall and window of the structure and then follow a path through the interior of the structure with a view of the bed room, the living room and a view (looking west) through the open door to the corridor. The second set of four views, at the bottom of each figure, provides a video view of the north east portion of the corridor and a view of the inside of the target room door. The thermal imaging cameras provide a view of the east corridor, looking north, and a view of the inside of the target room.

Figure 5.2.1-1 shows the conditions at the time of ignition. At this point, the six video views are clear and unobstructed. However, the thermal images provide limited thermal contrast because the surfaces in the view were at nearly equal temperature.

The images in Figure 5.2.1-2 were captured 60 s after ignition. The fire from the trash container spread to both the bed and the upholstered chair. A smoke layer formed in the bedroom, and the ceiling jet started to move down the hall. There was no smoke or change in thermal condition in the living room, target room or corridor at this time.

The images in Figure 5.2.1-3 were recorded at 120 s after ignition. The area involved in fire between the bed and the chair increased in size. The smoke layer was approximately 1.2 m (4 ft) thick throughout the bedroom, hall and living room. Smoke and heat had just started to flow into the corridor. The target room appears clear of smoke, however the target room IR view shows some limited heat infiltration along the top edge of the door between the hall and the target room.

Figure 5.2.1-4 shows the images recorded 60 s later at 180 s after ignition. The window opening had just been cleared after more than 75 % of the window opening was vented by the fire at 168 s after ignition. The flames can be seen flowing out of the window opening against the wind and blowing horizontal across the floor of the bedroom. Soot obscured the video views in the living room and both of the cameras in the corridor. The image from the corridor IR camera shows hot gases exiting the living room, filling the doorway top to bottom and impinging on the east wall of the corridor. Smoke and heat was flowing around the entire perimeter of the hall door into the target room, as shown in both the video and thermal image of the target room.

Figure 5.2.1-5 shows the conditions at 189 s after ignition. Flames are still flowing out of the top of the window opening. Only a glow could be seen in the bedroom. Horizontal flames are shown extending through the living room and out through the doorway into the corridor. Flames are shown around the top portion of the door and at the bottom edge of the door.

The images in Figure 5.2.1-6 were recorded at 200 s after ignition, just prior to the deployment of the large wind control device. The bedroom was fully involved with a post-flashover fire with some flames extending into the corridor. The thermal view of the corridor continued to show heat exiting the living room, filling the doorway from top to bottom, and at a high velocity. The thermal image was deteriorating due to the high thermal exposure. The target room video view showed less flame around the target room door, than the image from 11 s earlier. The thermal view shows the outlines of the reinforcing material inside the hollow core door, as the door had increased in temperature.

At 205 s after ignition, the wind control device was deployed and in place as shown in the outside view of Figure 5.2.1-7. The interior video views were obscured by soot. The thermal view of the corridor no longer showed any hot gas flows, only a hot gas layer. Conditions in the target room did not appear to have changed significantly in the 5 s since the images in Figure 5.2.1-6.

Figure 5.2.1-8 shows the conditions at 240 s after ignition, or approximately 75 s since deployment of the wind control device. The interior video views were still obscured by soot. The thermal image from the corridor was still saturated with heat but started to improve in clarity. In the target room the top of the door continued to burn and the thermal image captured the increased heat level of the door.

Figure 5.2.1-9 shows the conditions at 270 s after ignition, which was about one second after the curtain was removed from the window opening.

Figure 5.2.1-1. Experiment 2 ignition.

Figure 5.2.1-2. Experiment 2, 60 s after ignition.

Figure 5.2.1-3. Experiment 2, 120 s after ignition.

Figure 5.2.1-4. Experiment 2, 180 s after ignition.

Figure 5.2.1-5. Experiment 2, corridor flames, 189 s after ignition.

Figure 5.2.1-6. Experiment 2, WCD deployed, 200 s after ignition.

Figure 5.2.1-7. Experiment 2, WCD in place, 205 s after ignition.

Figure 5.2.1-8. Experiment 2, 240 s after ignition.

Figure 5.2.1-9. Experiment 2, WCD removed, 270 s after ignition.

Figure 5.2.1-10. Experiment 2, 300 s after ignition.

5.2.2 Heat Release Rate

Figure 5.2.2-1 shows the heat release rate time history for Experiment 2. The increase in measured heat release rate is delayed because for the first 100 s after ignition no heat or combustion products generated by the fire flowed out of the structure. The measured heat release rate increased only slightly prior to the failure of the window, this may be due in part to the a 6.8 m/s to 9.1 m/s (15 mph to 20 mph) wind which was flowing over and around the structure. After the window failed, at 167 s after ignition, the increase in heat release rate is clear. The heat release rate reached a peak of approximately 17 MW, 30 s after window failure. The large WCD was deployed and in place at 201 after ignition. This resulted in a significant decrease in heat release rate. Within 30 s after the WCD was in place the heat release rate dropped from approximately 17 MW down to approximately 1 MW. Approximately 10 prior to the removal of the WCD, the heat release rate started to increase. This increase is due to ignition of combustion products mixing with fresh air at the top of the exhaust vent stack. Once the WCD was removed the air flowed into the window and within seconds the visible fire in the bedroom increased until the entire room appeared fully involved. Manual activation of the safety sprinklers in the structure began at 293 s.

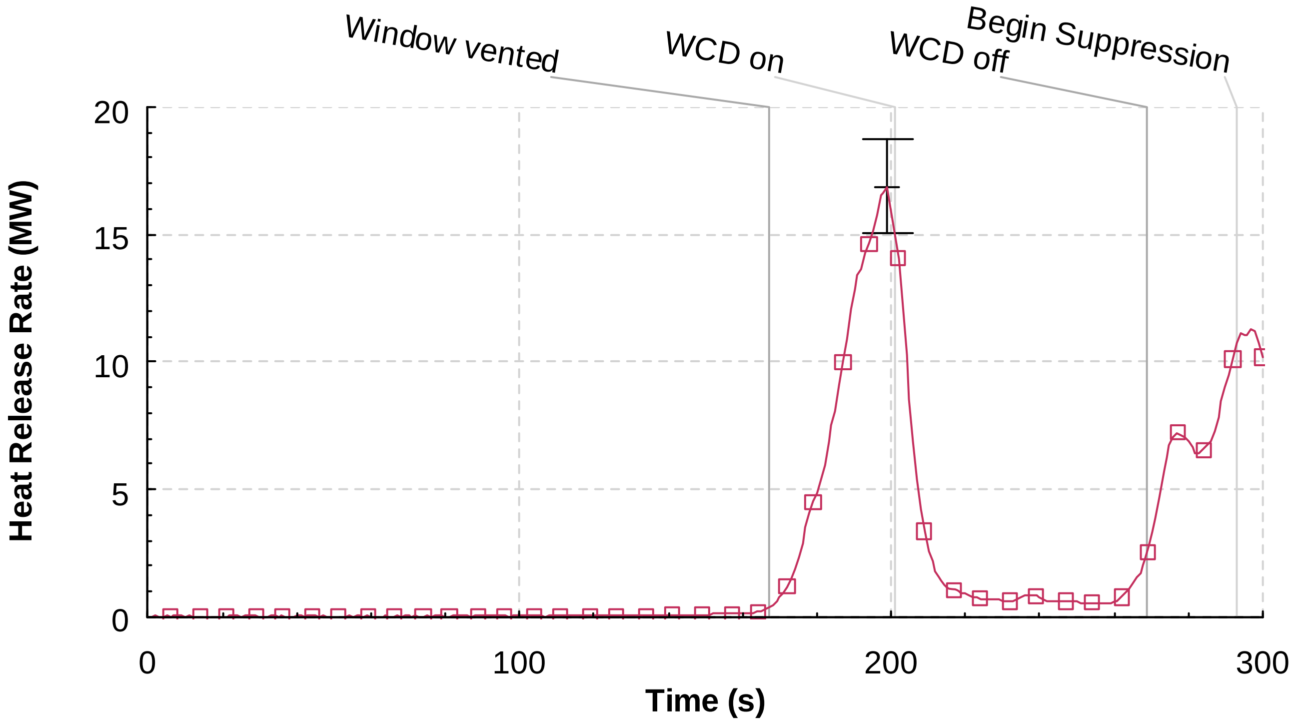

Figure 5.2.2-1. Heat release rate versus time, Experiment 2.

5.2.3 Temperatures

Figure 5.2.3-1 through Figure 5.2.3-12 provide the temperature measurements from the thermocouple arrays shown in Figure 4.1.3-1. The figures are given in order from the western most measurement point, the bed room window opening, and moving through the structure toward the east; bedroom, hall, living room, corridor, south and southwest portions of the corridor (closed end) and then to the north section of the corridor and ending with the exhaust vent. The last two temperature graphs have temperatures associated with the target room.

The three thermocouples located in the window opening, shown in Figure 4.1.3-1, provide insight into the ventilation conditions at the window. Prior to failure of the window at 167 s after ignition, there is no increase in temperature outside of the window. Once the window was vented, the temperatures increased, however the increase was small compared to Experiment 1. This is due to the cooling effect of the wind blowing air into the opening. After the WCD is deployed, the thermocouples were under the WCD and the temperatures increased. With the WCD in place there was localized burning occurring in the bedroom which may have resulted in the temperature spikes at approximately 240 s after ignition. The temperatures were in decline prior to the removal of the WCD and continued to decrease after the WCD was removed.

The measurements from the thermocouple array located in the center of the bedroom are given in Figure 5.2.3-2. Prior to the window failure, the temperatures in the bedroom increased from ambient conditions to a peak of approximately 700 ºC (1292 ºF) near the ceiling. At the same time, the temperatures, 2.13 m (7.00 ft) below the ceiling, were almost 100 ºC (212 ºF). After the window vented, the wind mixed and cooled the gases in the room. This resulted in temperatures that were all in the range of approximately 250 ºC to 300 ºC (482 ºF to 572 ºF). The thermocouple located 0.03 m (0.08 ft) below the ceiling was an exception as its temperature only decreased to approximately 500 ºC (932 ºF). This condition only last about 10 s, then the temperatures from the ceiling down to 1.52 m (5.00 ft) below the ceiling began to increase and stratify again. Flashover conditions were reached, based on temperatures from ceiling to floor being in excess of 600 ºC (1112 ºF), at approximately 190 s after ignition and 23 s after window failure. The WCD was deployed at 201 s. Within 40 s of deployment temperatures had decreased from in excess of 800 ºC (1472 ºF) to less than 400 ºC (752 ºF). The temperatures continued to decrease until the WCD was removed. Within 20 s of WCD removal, the bedroom was fully involved in flames again, as temperatures all increased to values in excess of 700 ºC (1292 ºF).

The data from the hall thermocouple array is presented in Figure 5.2.3-3. Prior to the window vent time, the temperatures increased and hot gas layer formed that extend from the ceiling down to at least 1.52 m (5.00 ft) below the ceiling. After the window vented, all of the temperatures more than doubled in less than 30 s, reaching a peak of approximately 800 ºC (1472 ºF) from the ceiling down to 2.13 m (7.00 ft) below the ceiling. The temperatures had reached a steady state at the time of WCD deployment. The impact of the WCD can be seen as the aggregate temperatures decreased from approximately 800 ºC (1472 ºF) to less than 300 ºC (572 ºF) within 70 s. When the WCD was removed, the temperatures decreased for a few seconds as the outside air flowed through the hall mixing with products of combustion. Then the temperatures increased again, although they did not reach temperatures that are consistent with the transition to flashover.

The living room had two thermocouple arrays, a corner array and an array in the center of the living room which was in the direct flow path between the hall and the corridor. The temperatures from the corner array are provided in Figure 5.2.3-4. The temperatures follow similar trends as the temperatures in the hall; however, the peak temperatures are lower. The impact of the vented window caused a rapid increase in temperature and the deployment of the WCD caused decreased temperatures. After deployment of the WCD, the temperature range between the ceiling and floor began to increase as the gases in the room cooled. In less than 70 s, the peak temperatures were reduced by 50 % or more. Removal of the WCD produced a pronounced decrease in temperature, approximately 100 ºC (212 ºF) near the ceiling, followed by a rapid increase.

The temperature measurements from the center of the living room are shown in Figure 5.2.3-5. Again the temperature responses to the fire and WCD events are similar to those in the hall and the corner of the living room. However the living room temperature values are a closer match to the hall values in terms of magnitude and a narrow temperature range at any given time after window failure.

Figure 5.2.3-6 gives the corridor center position thermocouple array measurements, which is located just east of the doorway from the living room to the corridor. Temperatures indicative of a hot gas layer, extending from the ceiling down to 1.22 m (4.00 ft) below the ceiling, existed just prior to the window being vented. After the window vented, the temperatures from the ceiling to the floor increased to more than 700 ºC (1292 ºF) within 20 s. After WCD deployment temperatures at this position decreased to less than 300 ºC (572 ºF) within 70 s. After the WCD was removed the temperatures increased with hot layer temperatures of approximately 650 ºC (1202 ºF) and temperatures closer to the floor were approximately 480 ºC (896 ºF).

The temperature measurements from the thermocouple arrays in the south and southwest areas of the corridor are given in Figure 5.2.3-7 and Figure 5.2.3-8. These positions are not in the direct flow path from the wind opening to the ceiling vent in the northwest corridor. Again these measurements follow the general trends of the previously presented arrays. Some differences at the corridor south position would include, a shorter time at peak temperatures after the window vented, a lower temperature range post WCD deployment and a very pronounced decrease in the upper layer temperatures after the WCD was removed. When the temperatures increased again as a result of WCD removal the temperatures only reached a peak of approximately 400 ºC (752 ºF).

Looking at Figure 5.2.3-8, the peak temperatures are half of those shown at the corridor south position. After the deployment of the WCD the temperatures decreased to half of the peak values, before temperatures increased in response to the WCD removal. Note that two of the thermocouple channels did not function properly in this experiment. It appears that the thermocouple at 0.91 m (3.00 ft) below the ceiling was shorted at a location that remained at ambient temperature and it is thought that the thermocouple at 1.22 m (4 ft) below the ceiling may have been in contact with a pressure sample line or a radiometer cooling line until it was dislodged at approximately 190 s and began measuring the gas temperature at that location.

The temperature measurements from the corridor north position are displayed in Figure 5.2.3-9. The stratified temperatures at that position yielded a peak temperature of less than 150 ºC (302 ºF) prior to the venting of the window. Within 30 s after the window failed, the temperatures at this position increased to an aggregate average of approximately 650 ºC (1202 ºF). The deployment of the WCD resulted in a significant decrease of the temperatures, such that the peak temperatures were approximately 250 ºC (482 ºF) or less. Temperatures increased to more than 500 ºC (932 ºF) with 25 s of the removal of the WCD.

The temperatures at the exhaust vent are given in Figure 5.2.3-10. All of the temperatures are consistent with the trend of and track well with the temperatures from the north corridor position.

In Figure 5.2.3-11 the temperatures of two single thermocouples in contact with the knobs on the target room door are shown. The temperature on the knob in the hall lags the temperatures in the hall due to the initial conduction loss to the knob and then surpasses the temperatures due to the hall side of the door burning. The thermocouple on knob in the target room increased for a brief period, then it appears that it became detached from the knob and came to rest against the wall at a lower level in the room.

The measurements from the thermocouple array in the center of the target room are given in Figure 5.2.3-12. A hot gas layer, 0.61 m (2.00 ft) thick, has formed within 200 s after ignition. During the time the WCD was in place, only the temperatures close to the ceiling increased as smoke an flames burned around the top edge of the door. After the WCD was removed, cool air pushed in through the gap at the top of the door, which caused the upper thermocouples to cool. This was followed by increased flames coming from the door and the opening as it burned away, visible in Figure 5.2.1-10, which resulted increased temperatures.

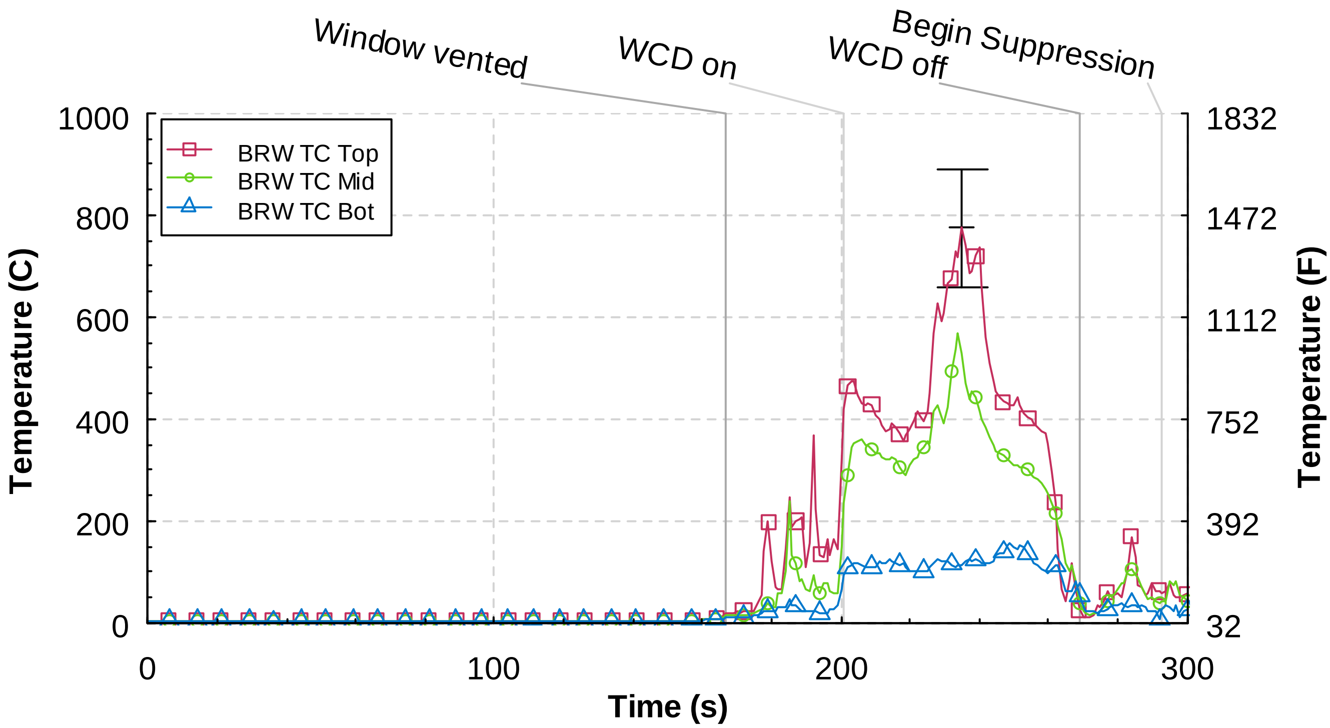

Figure 5.2.3-1. Temperature versus time from the bedroom window (BRW) thermocouple array, Experiment 2.

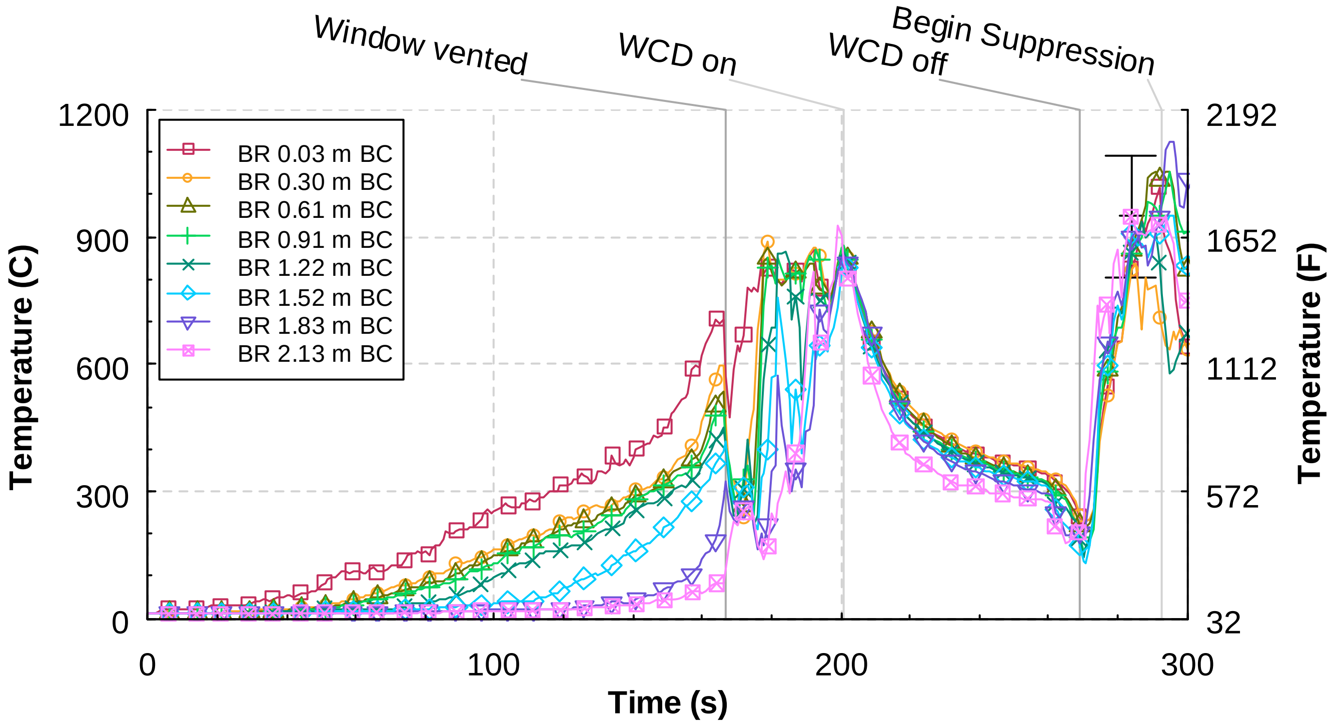

Figure 5.2.3-2. Temperature versus time from the bedroom (BR) thermocouple array, Experiment 2.

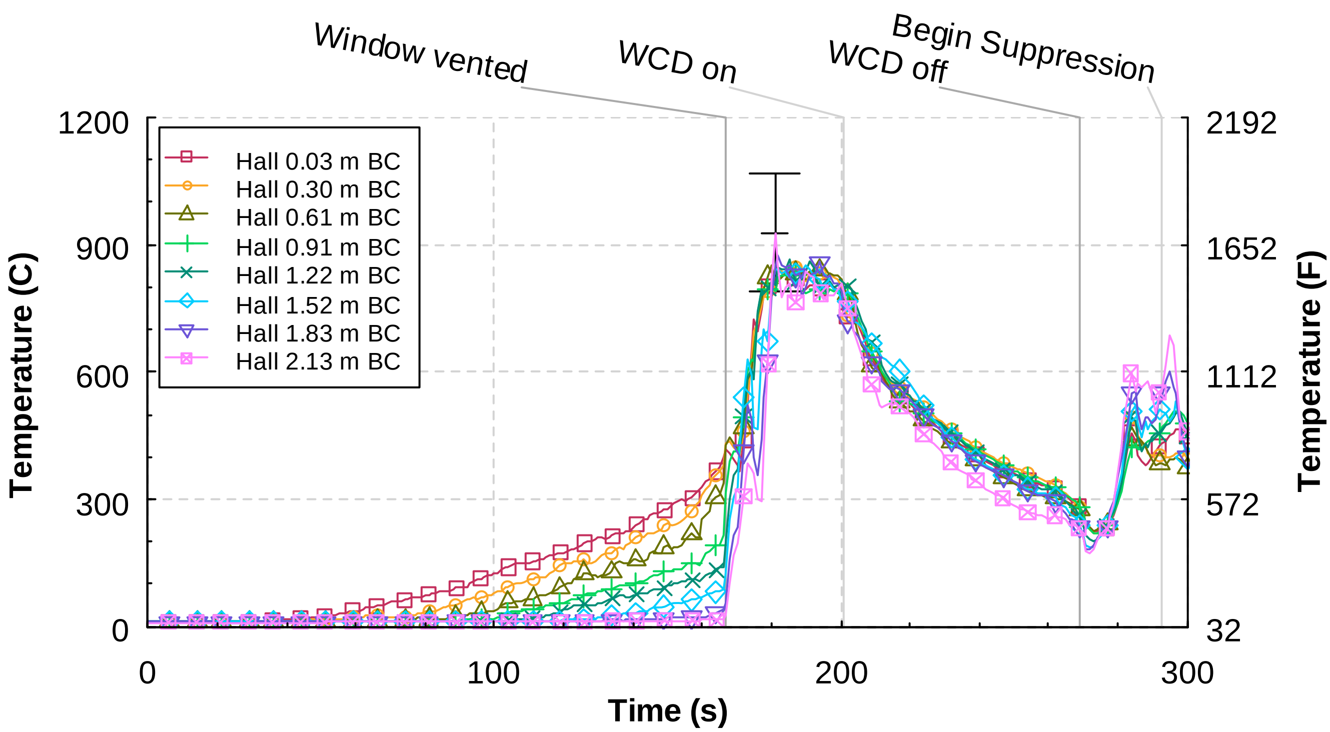

Figure 5.2.3-3. Temperature versus time from the hall thermocouple array, Experiment 2.

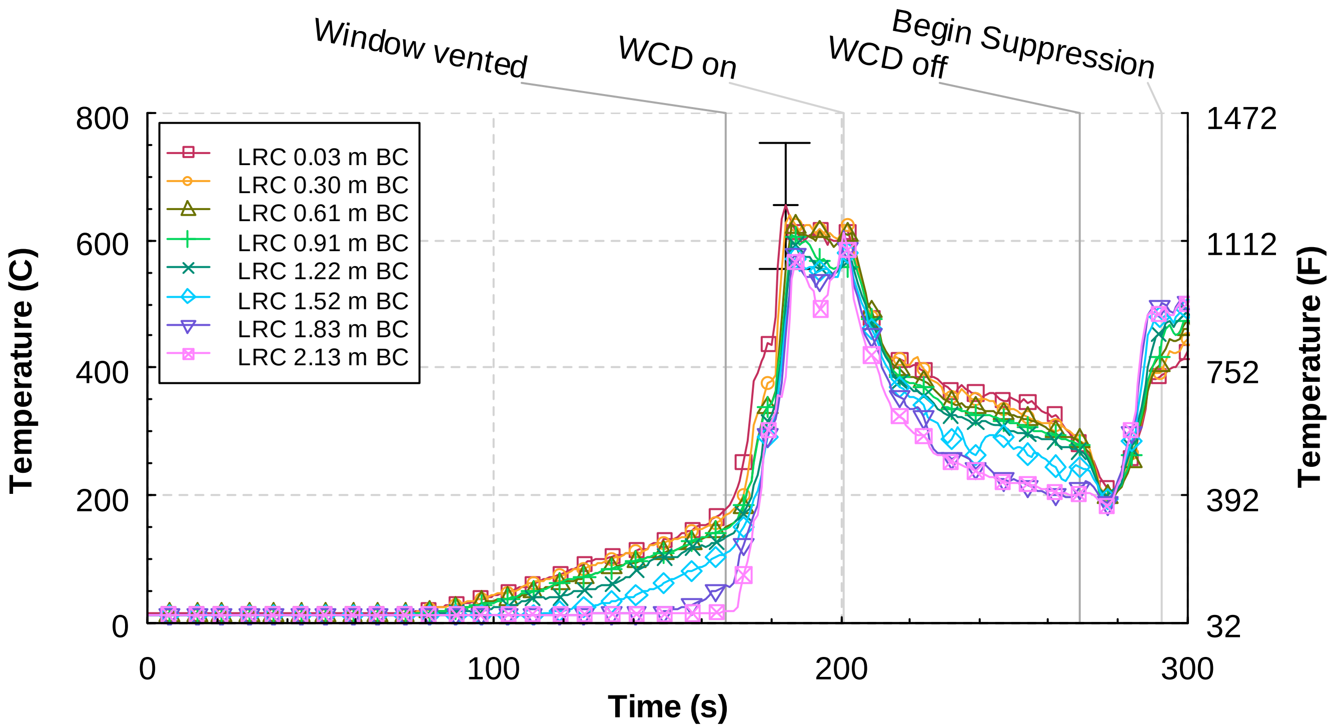

Figure 5.2.3-4. Temperature versus time from the living room corner (LRC) thermocouple array, Experiment 2.

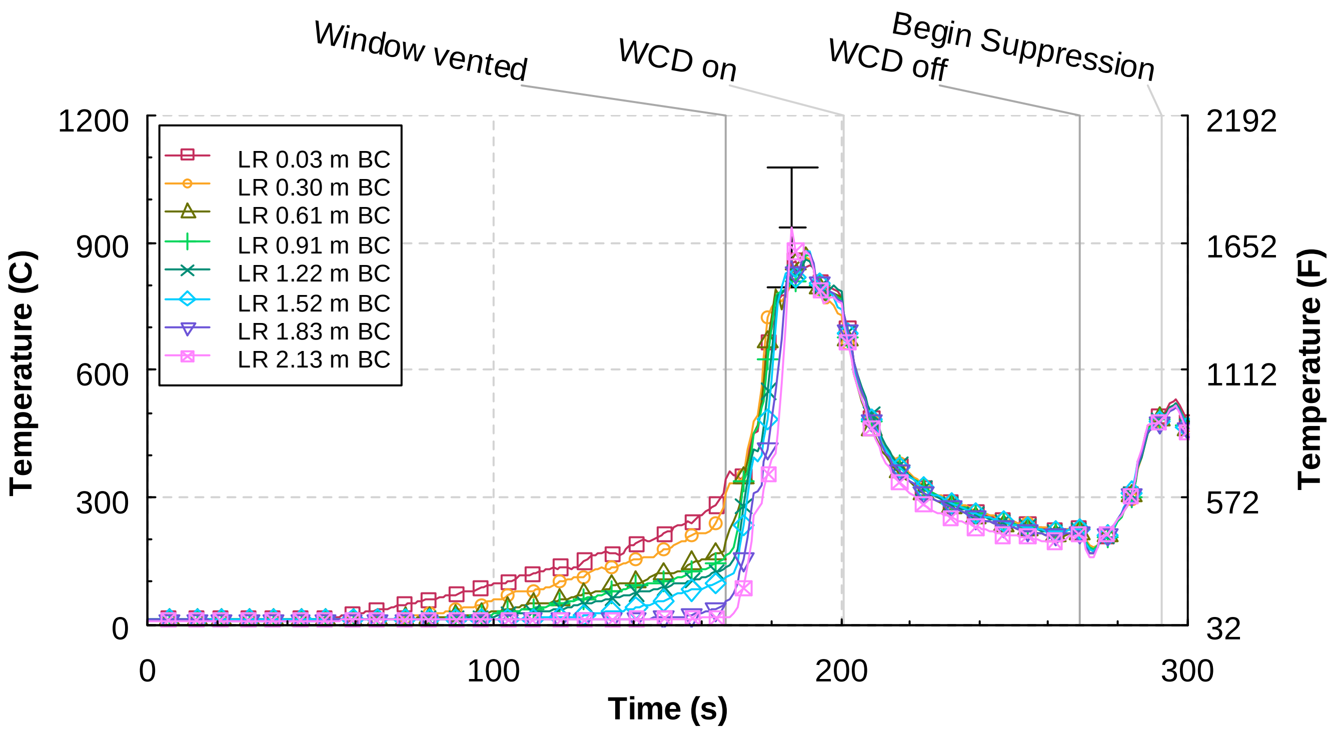

Figure 5.2.3-5. Temperature versus time from the living room (LR) thermocouple array, Experiment 2.

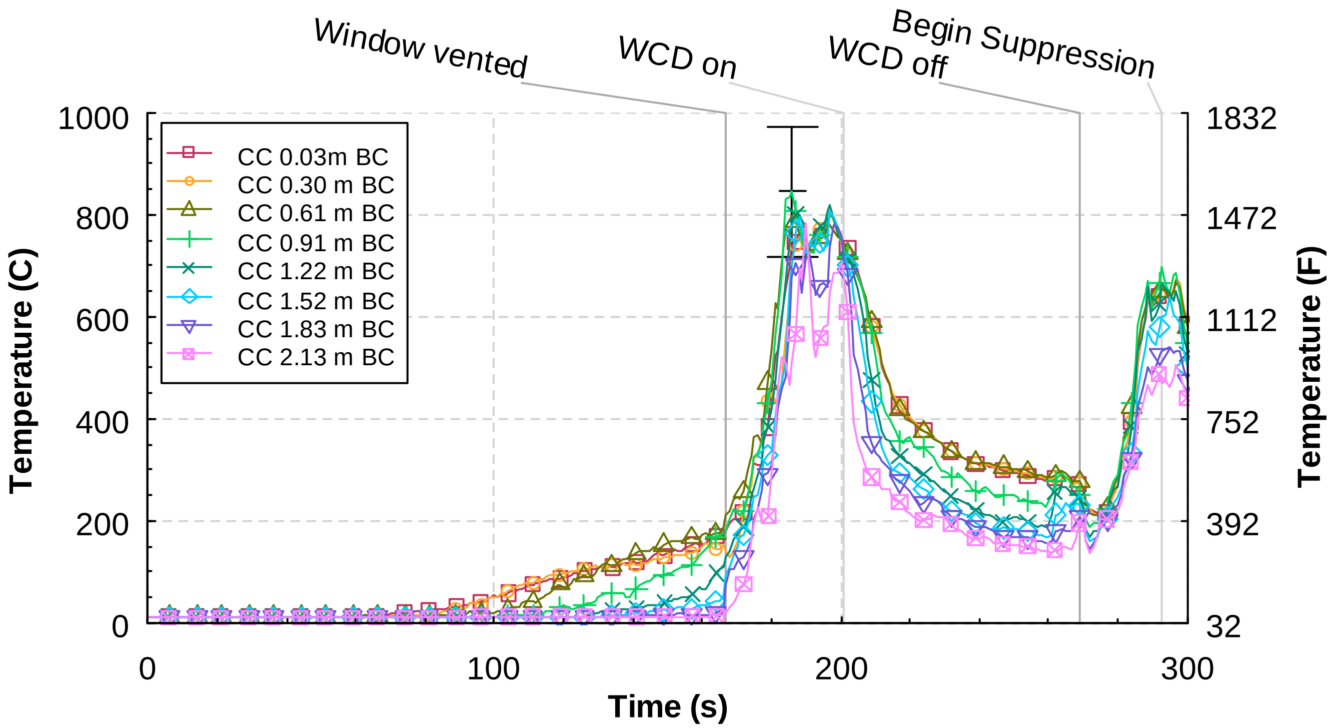

Figure 5.2.3-6. Temperature versus time from the corridor center (CC) thermocouple array, Experiment 2.

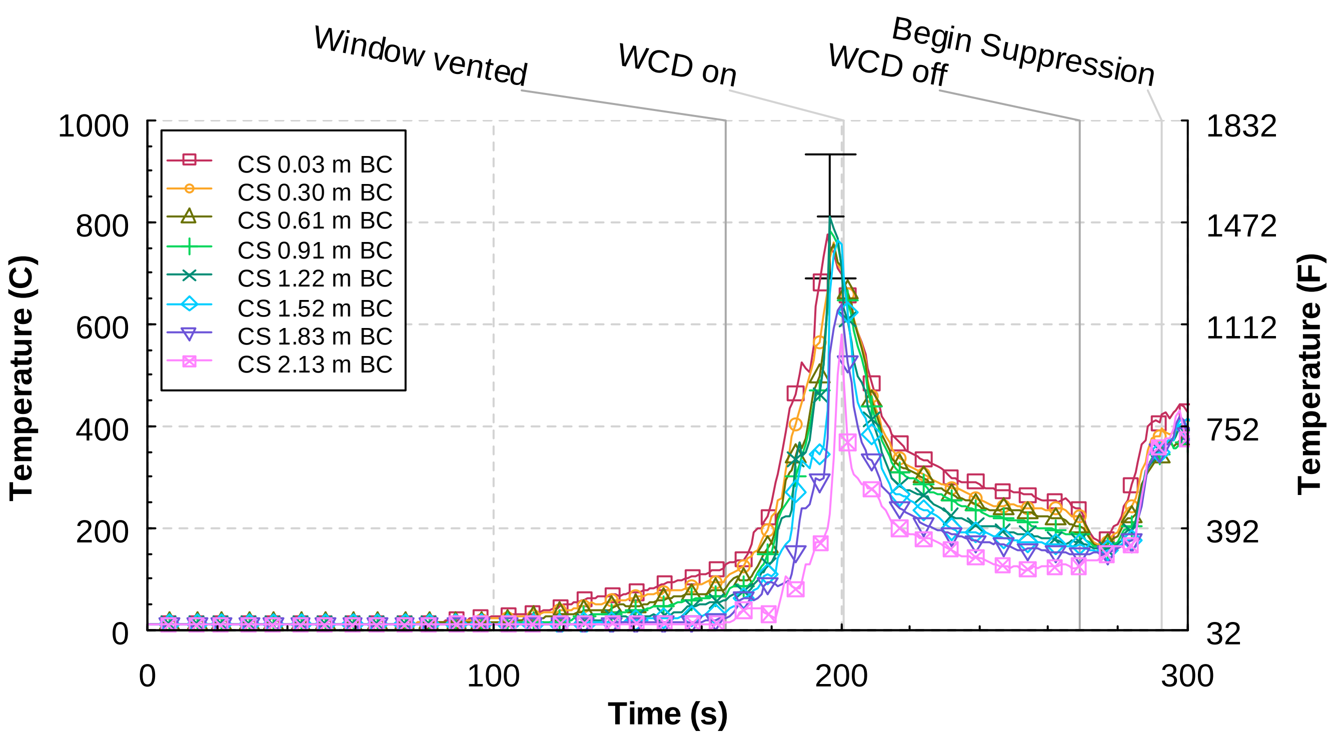

Figure 5.2.3-7. Temperature versus time from the corridor south (CS) thermocouple array, Experiment 2.

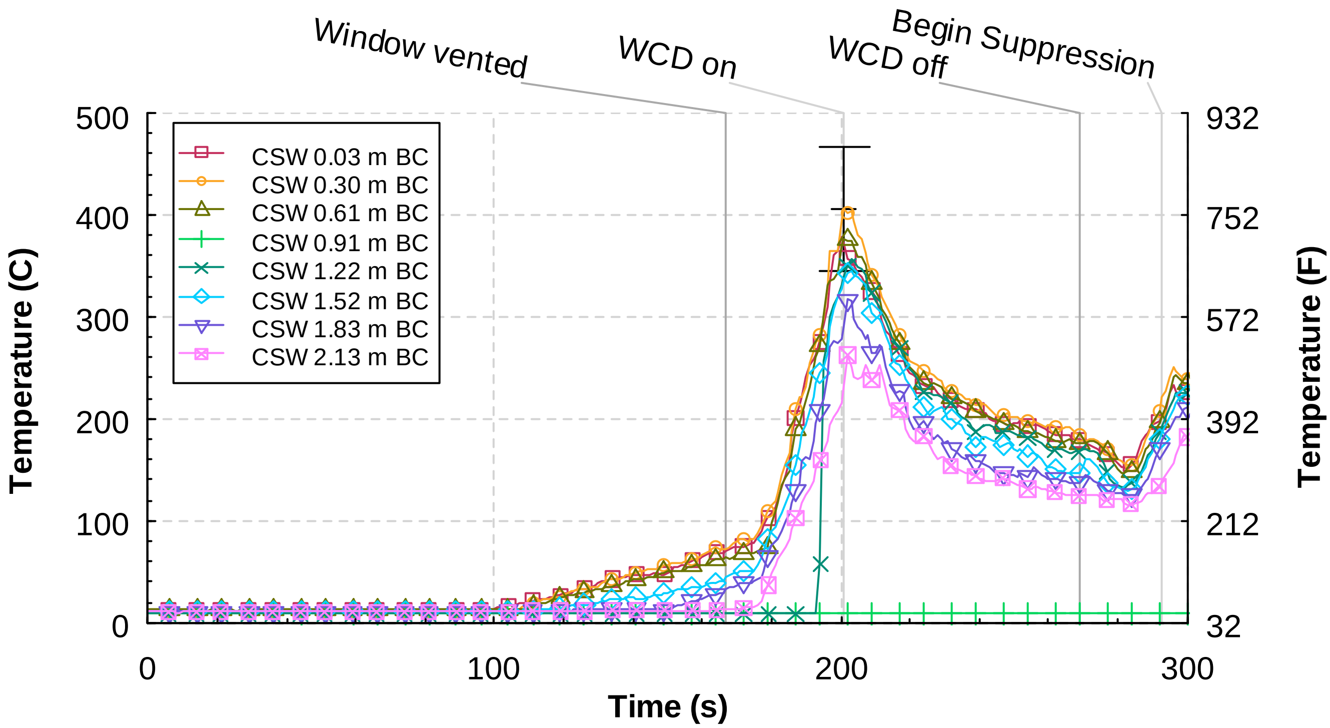

Figure 5.2.3-8. Temperature versus time from the corridor southwest (CSW) thermocouple array, Experiment 2.

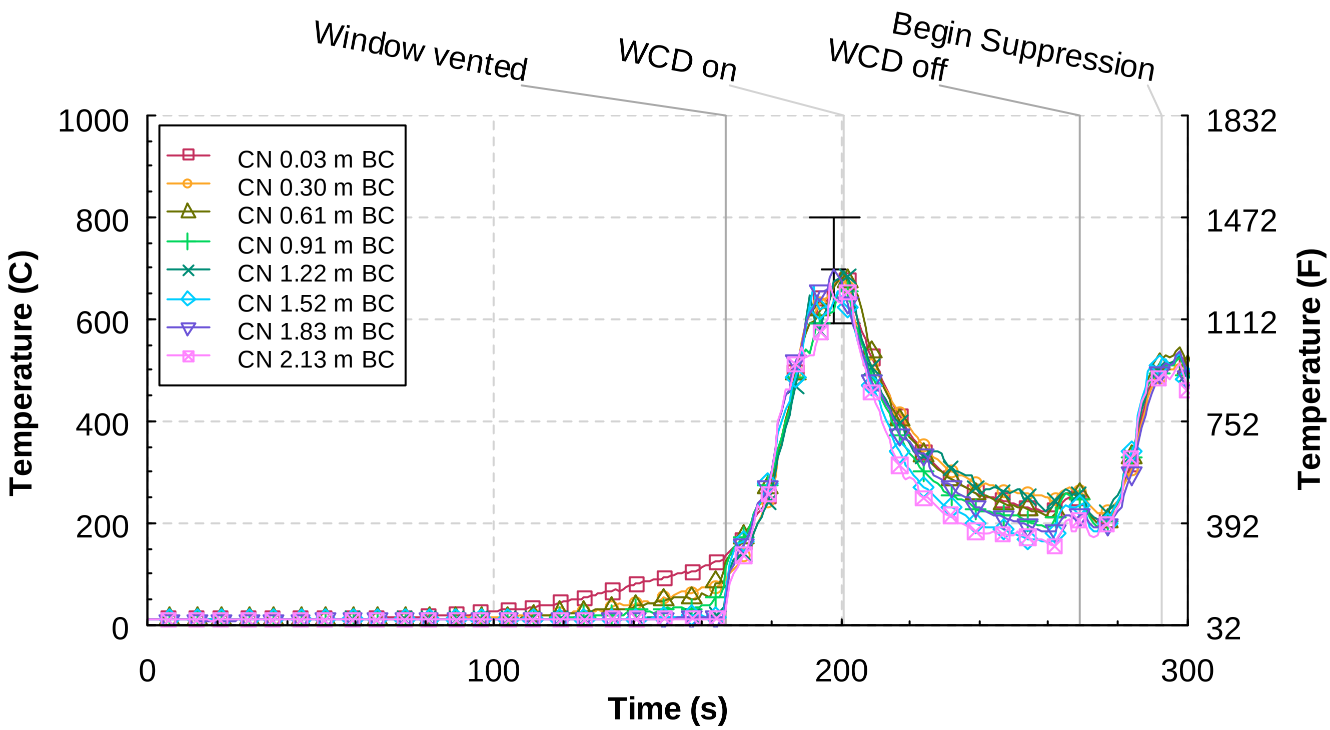

Figure 5.2.3-9. Temperature versus time from the corridor north (CN) thermocouple array, Experiment 2.

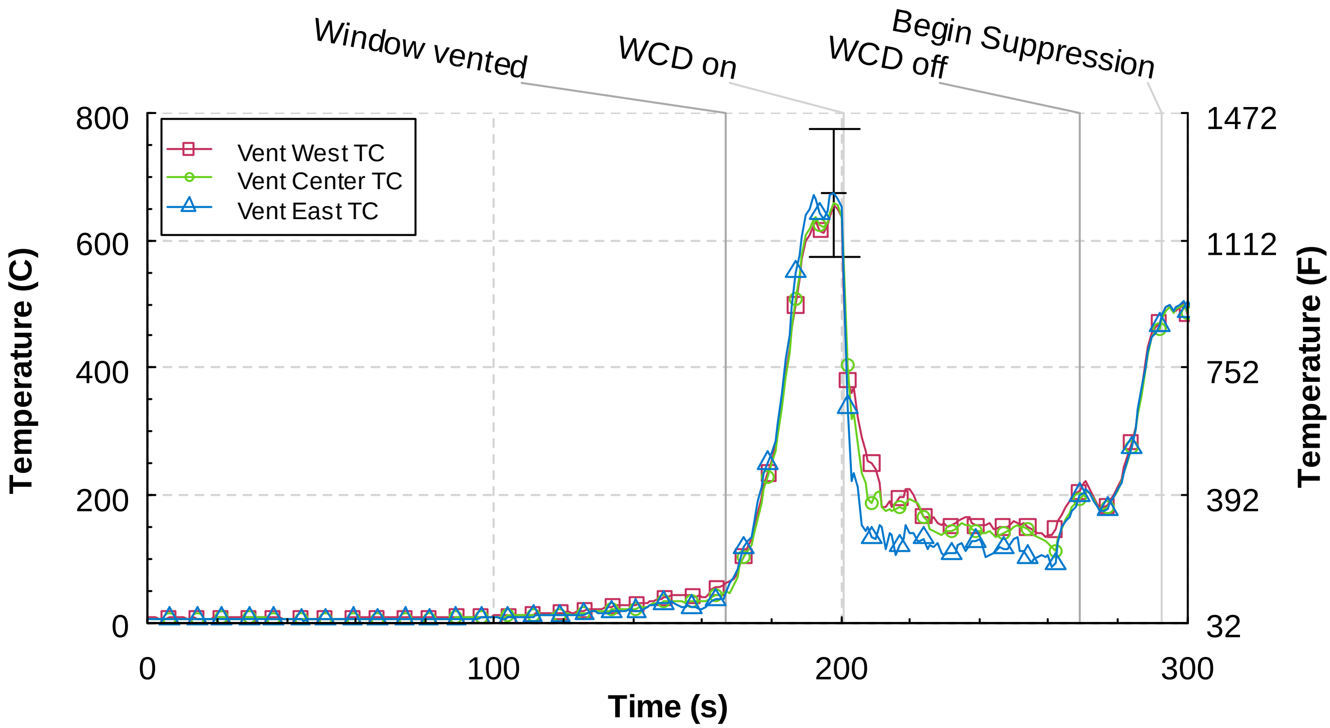

Figure 5.2.3-10. Temperature versus time from the ceiling vent thermocouple array, Experiment 2.

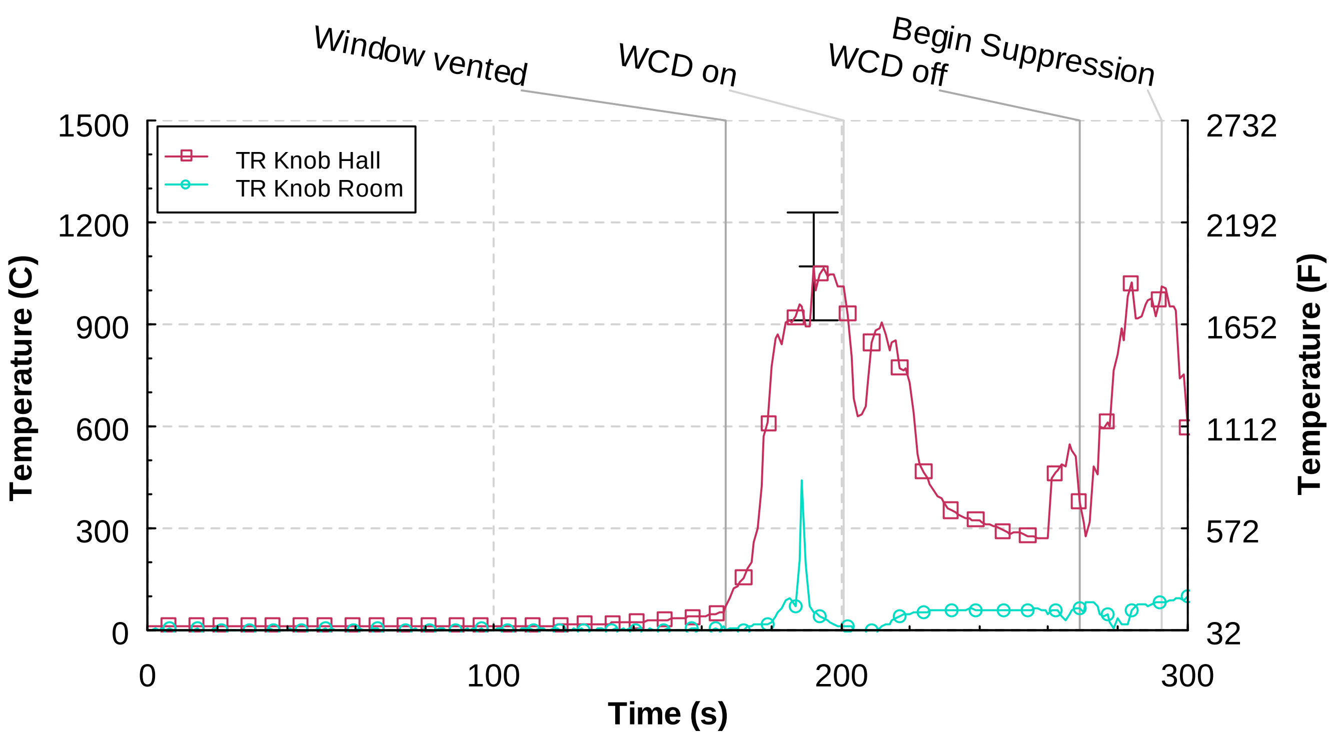

Figure 5.2.3-11. Temperature versus time from the target room (TR) door knobs, Experiment 2.

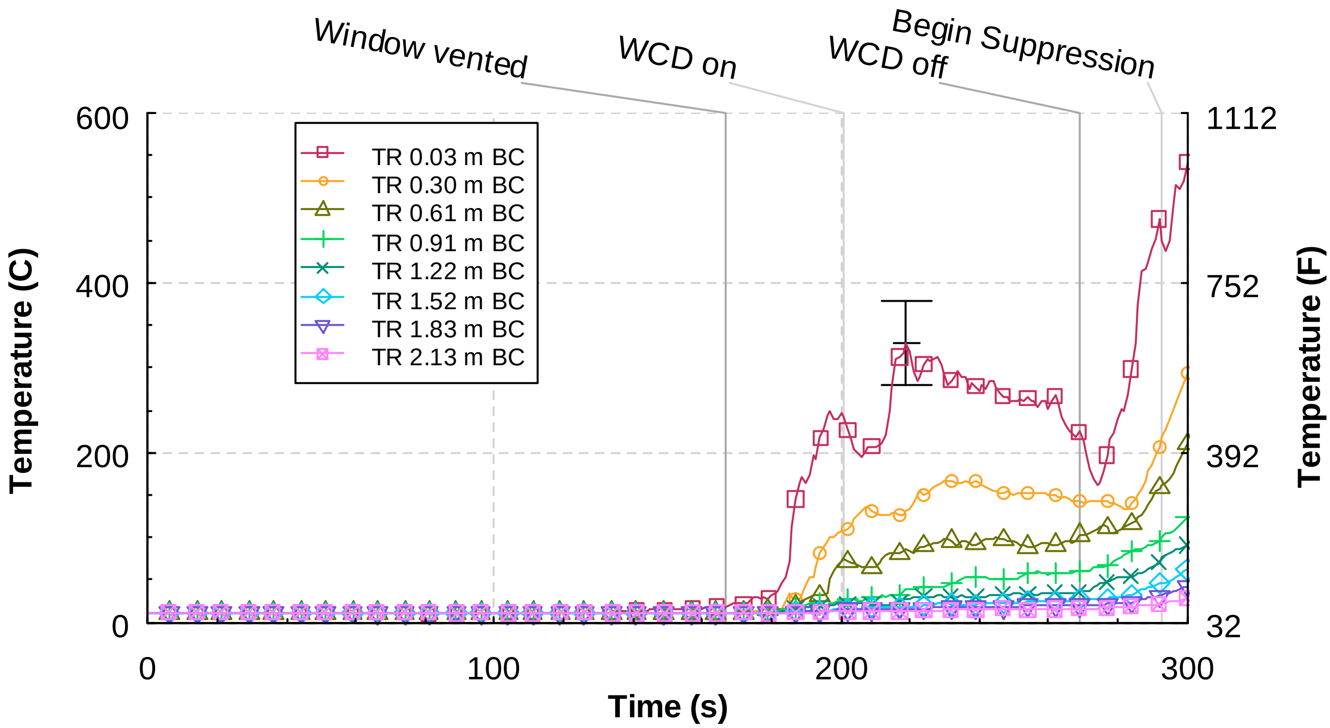

Figure 5.2.3-12. Temperature versus time from the target room (TR) thermocouple array, Experiment 2.

5.2.4 Heat Flux

Figure 5.2.4-1 shows the measurements from the heat flux gauges located in the bedroom, living room and three locations in the corridor. The heat flux in the bedroom exceeded 20 kW/m^2 just prior to the venting of the window. Just after the window vented, the heat flux in the bedroom decreased but the heat fluxes at the hall and corridor locations increased as the wind moved the hot gases through the structure.

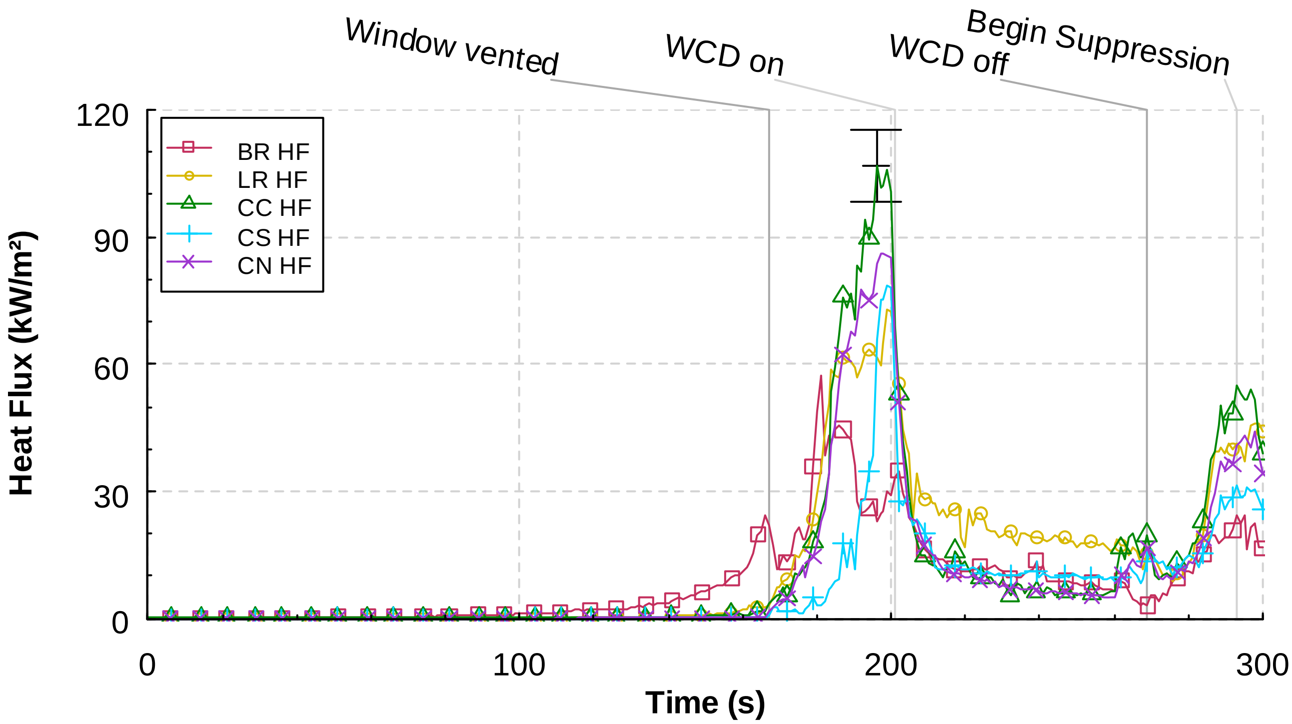

Figure 5.2.4-1. Heat flux versus time at five locations, Experiment 2.

5.2.5 Pressure

The pressure measurements from the bedroom, hall, living room, the northwest corridor and the southwest corridor are provided in Figure 5.2.5-1. The pressures in the structure began to exhibit negative values from approximately 100 s after ignition until the window began to fail. As the window was completely vented at 167 s, the pressures continued to increase for another 10 s. The peak pressure reached was approximately 50 Pa in the bedroom. The lowest pressure was in northwest section of the corridor under the ceiling vent. As the fire spread through the structure, the pressures began to decrease.

After the WCD was deployed, all of the pressures in the structure transitioned to uniform negative value of approximately -25 Pa. The measurements leveled off at approximately -15 PA, just before the removal of the WCD began. The complete removal of the WCD at 269 s after ignition, resulted in the pressure returning to values very similar to those prior to WCD deployment.

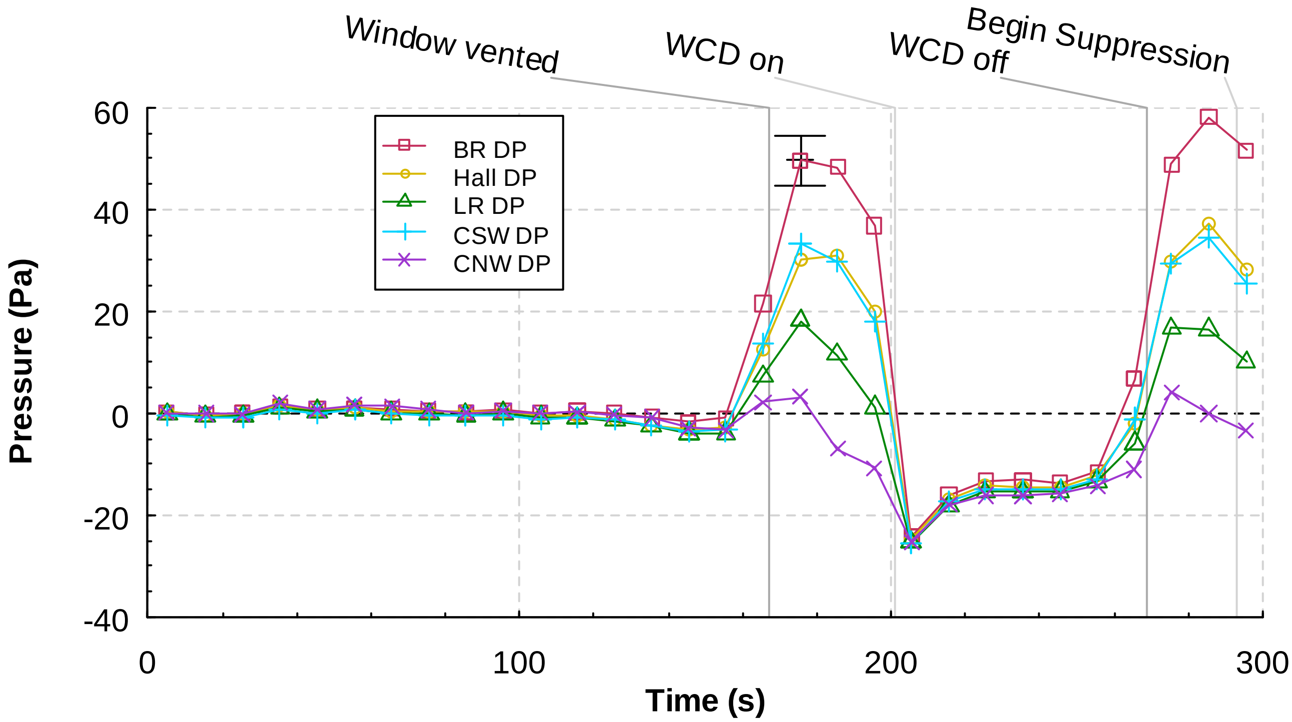

Figure 5.2.5-1. Pressure versus time at five locations, Experiment 2.

5.2.6 Velocities

The velocity measurements from the bedroom window, hall, south corridor, north corridor and ceiling vent locations are given in Figure 5.2.6-1 through Figure 5.2.6-5. The bedroom velocities are positive for flow into the structure. As the window vented, the velocities at the middle and bottom window position show velocities in excess of 1.5 m/s (3.4 m/s), while the top bi-directional probe has a lower value due to the flames and hot gases pulsing out that portion of the window. Once the WCD was deployed, the measurements at the window are not considered reliable as the WCD is pressing against the upwind side of the probe and the pressures in the bedroom decreased significantly as shown in Figure 5.2.5-1.
After the WCD was removed the flow pattern in the window returned to a similar state as before the WCD was deployed, although the magnitudes were more extreme.

Figure 5.2.6-2 displays the velocities measurements taken at the hall array. The top probe is located 0.3 m (1.0 ft) below the ceiling. This probe is in the wake of the doorway lintel which extends down 0.4 m (1.3 ft) below the ceiling, hence the lower velocity relative to the other two locations. The peak values of the two lower probes are approximately 7 m/s (15.4 mph) and 9 m/s (19.8 mph). After the WCD was deployed the velocities in the hall decreased to less than 2 m/s (4.4 mph) in less than 60 s. Removal of the WCD resulted in the velocities returning to near pre-deployment values.

Figure 5.2.6-3 shows the measurements from the south corridor bi-directional probe array. At this location the positive flow direction is South. Between 80 s and 160 s after ignition, the velocity at the top probe increased as a result of the ceiling jet moving out of the living room doorway. As the window failed, the initial push of cool air was followed by the ceiling jet/hot gas flow being established for the upper two probes while the probe near the floor shows evidence of recirculation. After the WCD was deployed, all of the velocities at this location settled into the range of 0 m/s to 1 m/s (2.2 mph). When the WCD was removed, the measurements indicated that the flow reversed, with the upper probes showing a northern flow while the probe near the floor shows a southern flow.

The data from the bi-directional probe array in the north corridor position, Figure 5.2.6-4, has more common flow profile. Prior to window failure, the flows at the south and north corridor positions are very similar. After the window is vented, the flow are very different. The bulk flow at the north corridor position is uni-directional, with the maximum value at the center location and similar values at near the ceiling and floor boundaries. The peak velocities at the north position are two to three times the magnitude of those at the south position. The velocities at the north corridor position also showed a significant reduction when the WCD was deployed. The velocities decreased to 1 m/s (2.2 mph) or less before the WCD was removed, at which time the velocities increased again.

The velocities at the exhaust vent position are similar to each other, within experimental uncertainty, throughout the duration of the experiment. Peak values, prior to WCD deployment, were approximately 8.5 m/s (18.7 mph). The deployment of the WCD reduced the velocities out of the structure to less 1.5 m/s (3.3).

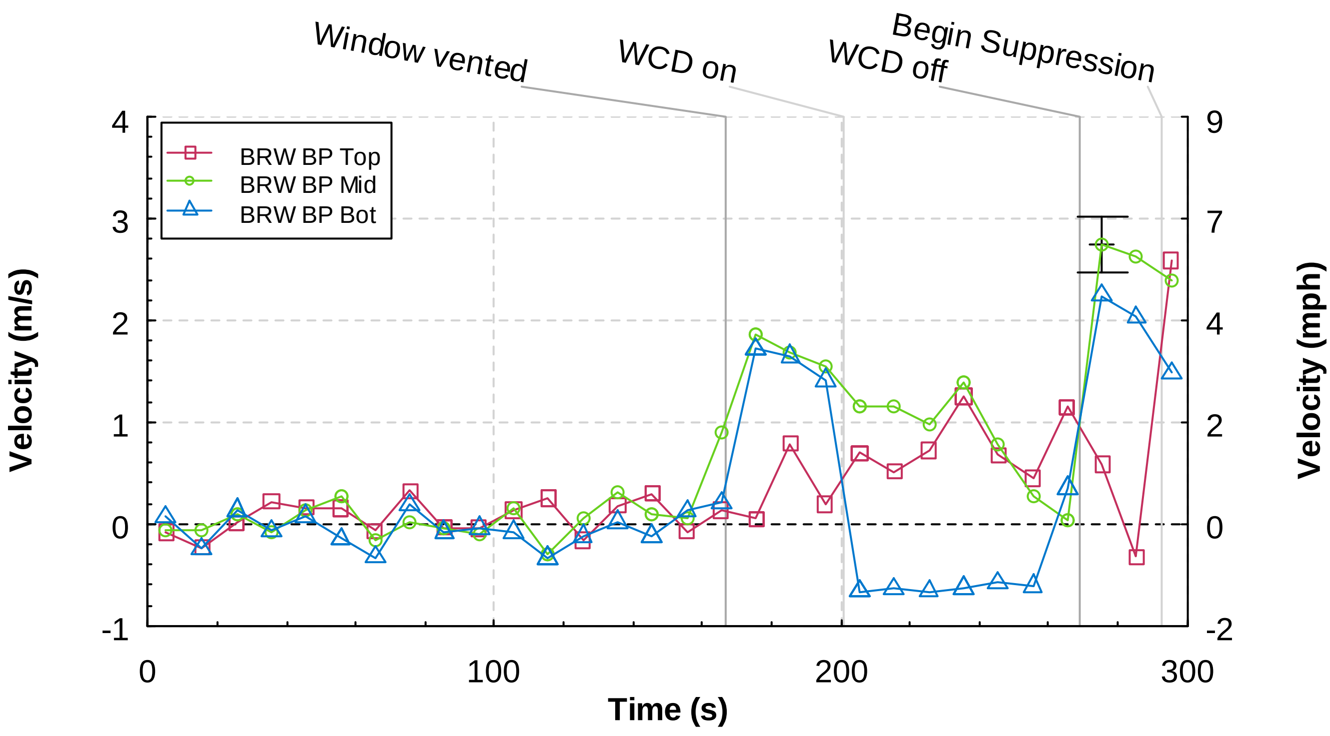

Figure 5.2.6-1. Velocity versus time from the bedroom window (BRW) bi-directional probe array, Experiment 2.

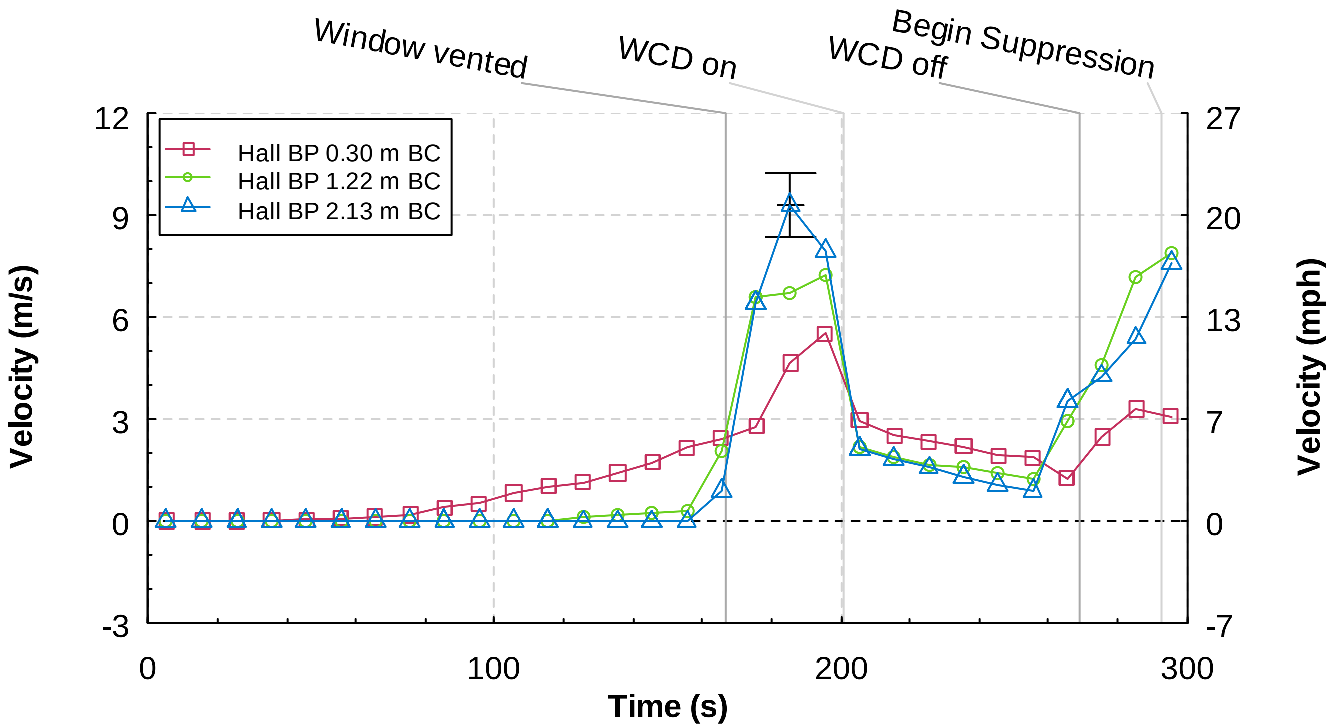

Figure 5.2.6-2. Velocity versus time from the hall bi-directional probe array, Experiment 2.

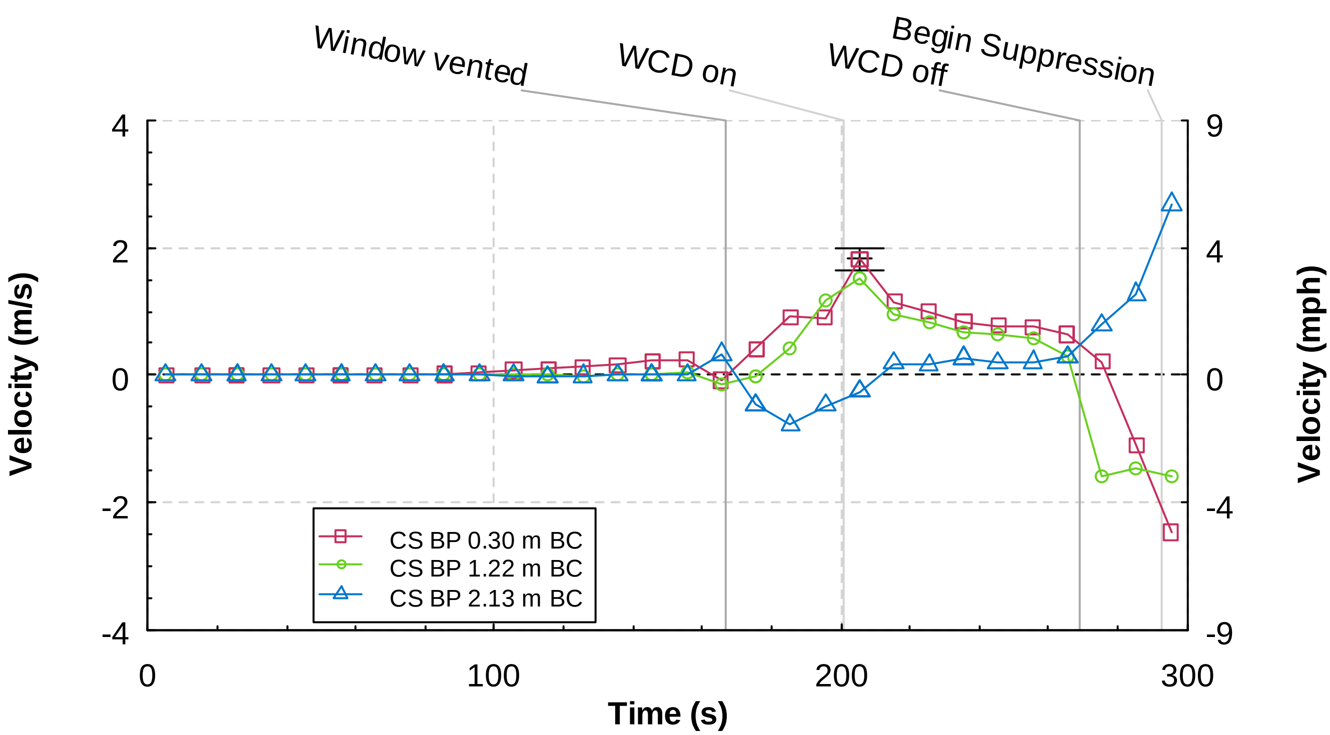

Figure 5.2.6-3. Velocity versus time from the corridor south (CS) bi-directional probe array, Experiment 2.

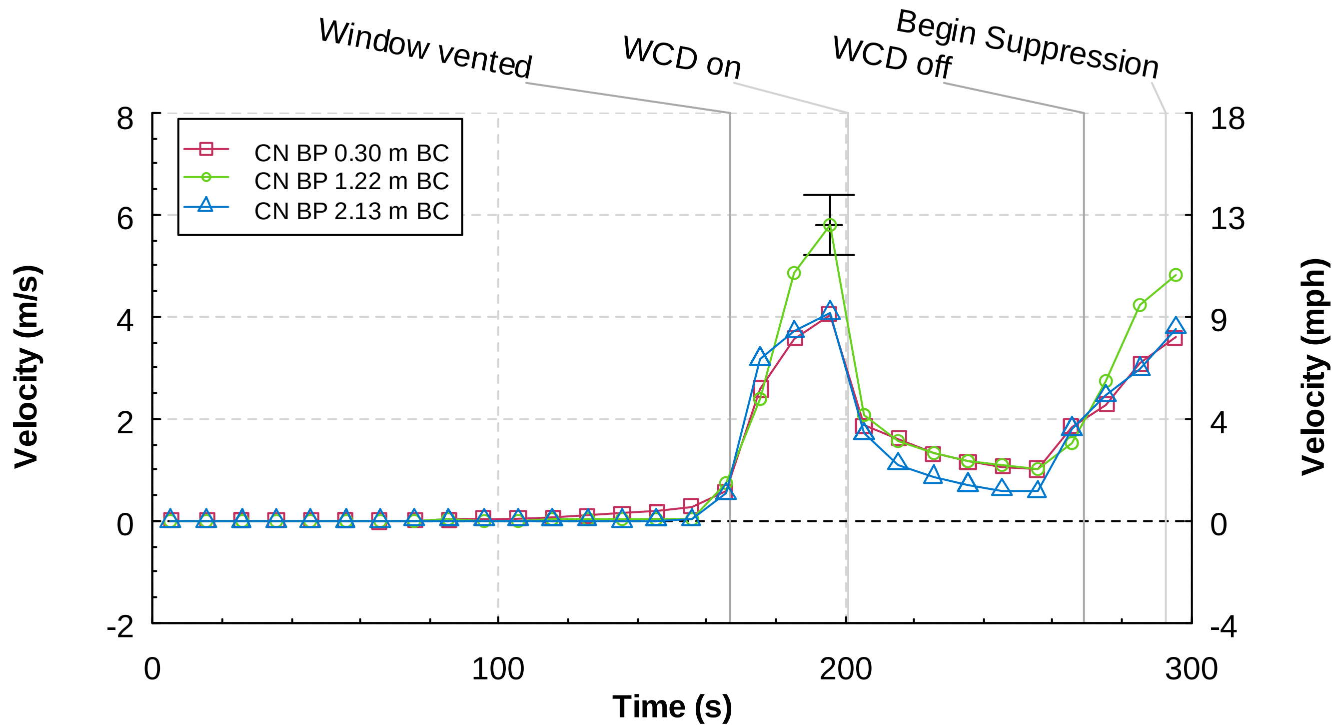

Figure 5.2.6-4. Velocity versus time from the corridor north (CN) bi-directional probe array, Experiment 2.

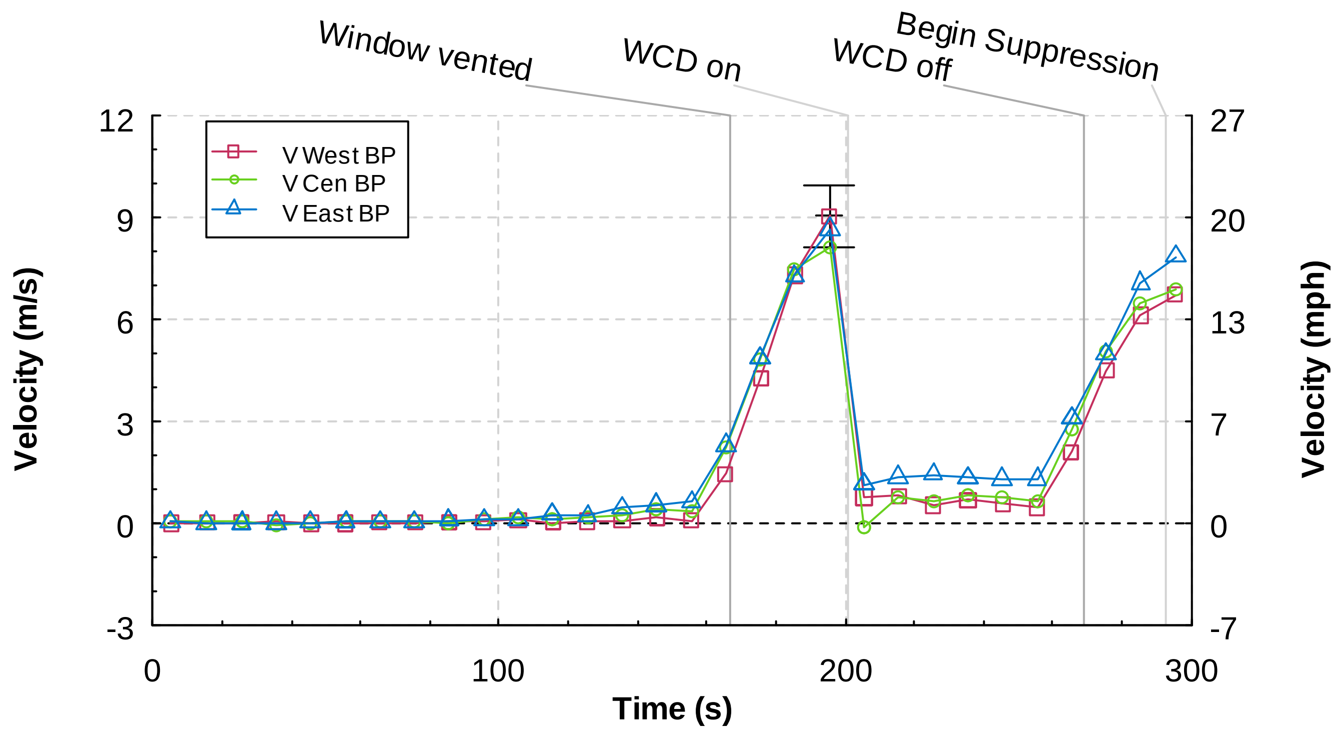

Figure 5.2.6-5. Velocity versus time from the ceiling vent (V) bi-directional probe array, Experiment 2.

5.2.7 Gas Concentrations

The gas concentration measurements are given in Figure 5.2.7-1 through Figure 5.2.7-4. The first two figures contain the measurements from the upper and lower bedroom probes and the last two figures have the measurements from the bedroom. The upper sampling positions are located 0.61 m (2.00 ft) below the ceiling and the lower sampling positions are located 1.83 m (6.00 ft) below the ceiling. Total hydrocarbons were only measured for the upper locations.

The upper bedroom location measurements of the oxygen, carbon dioxide, carbon monoxide and total hydrocarbons are shown in Figure 5.2.7-1. The trends of the gases continued in the same direction from ignition until the WCD was removed. After the WCD was removed the fresh air being pushed in the window caused the gases to reverse direction.

The lower bedroom location measurements are given in Figure 5.2.7-2. Onset of oxygen depletion and carbon dioxide and carbon monoxide generation at this position is delayed until the combustion products fill the upper portion of the room. After the window began to fail the gas concentrations began to change at a faster rate. The oxygen and consequently the carbon dioxide began to oscillate after the window was vented. Once the WCD was deployed the oxygen concentration drops to near 0 while the carbon dioxide increased to approximately 15 % and the carbon monoxide exceeded 5 %. After the WCD was removed, the oxygen level rebounded to near 18 %. The carbon dioxide and carbon monoxide both decreased.

The gas concentrations from the upper sampling position in the living room are shown in Figure 5.2.7-3. The trends and magnitudes of all of the gases measured are very similar to those from the upper bedroom position.

The measurements from the lower living room gas sampling position are shown in Figure 5.2.7-4. at this location the gas concentrations did not change from the initial values until the window began to fail. Within 30 s after the window was vented, the oxygen decreased to less than 8 %. The carbon dioxide and the carbon monoxide increased during this same period, reaching peak values of approximately 17 % and 4 % prior to deployment of the WCD. After the WCD was deployed, the oxygen began to increase and the other two gases began to decrease. The rates of respective increase and decrease sped up after the WCD was removed. Those trends began to reverse just prior to suppression.

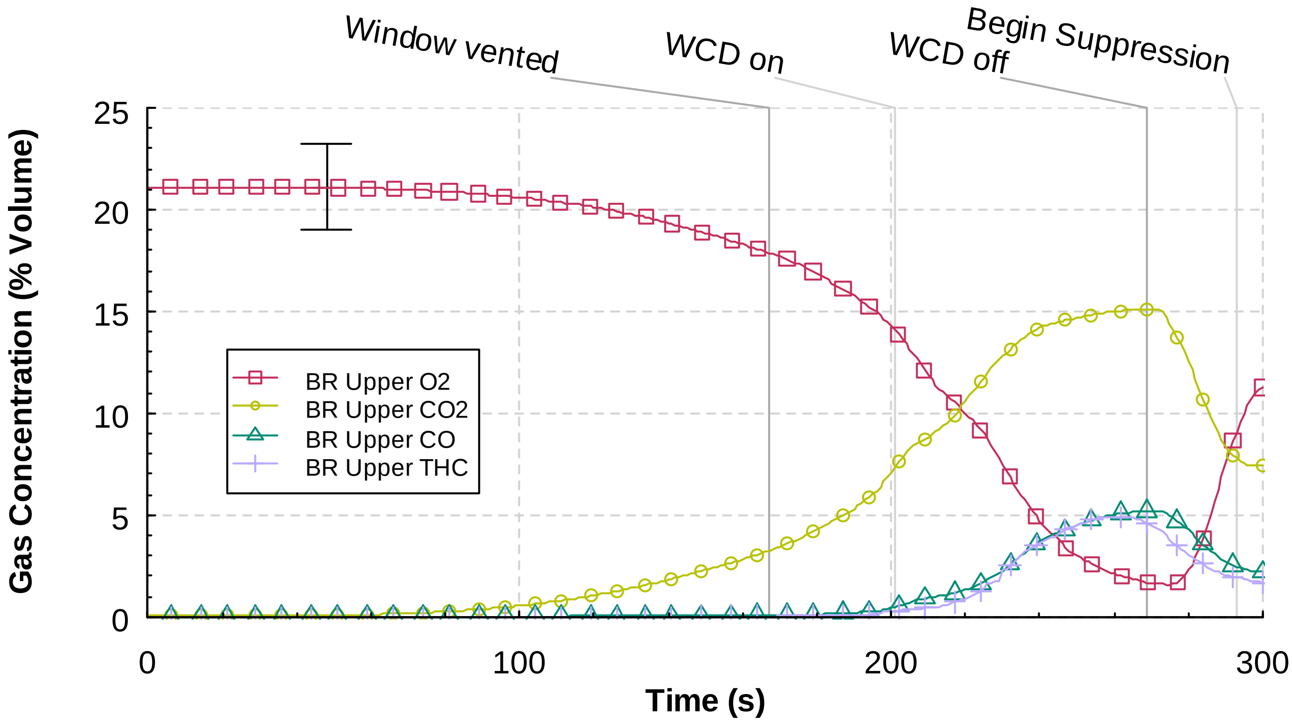

Figure 5.2.7-1. Oxygen, carbon dioxide, carbon monoxide, and total hydrocarbon percent volume versus time from the upper bedroom (BR) sampling location, Experiment 2.

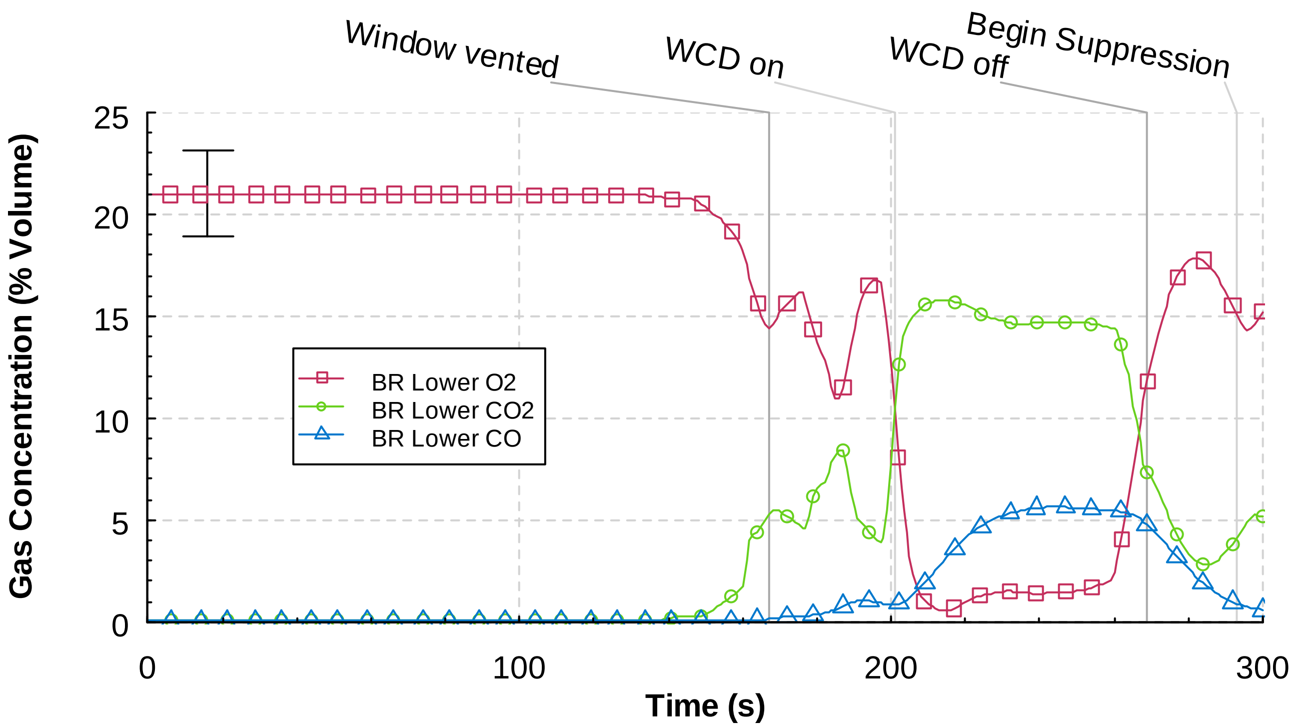

Figure 5.2.7-2. Oxygen, carbon dioxide, and carbon monoxide percent volume versus time from the lower bedroom (BR) sampling location, Experiment 2.

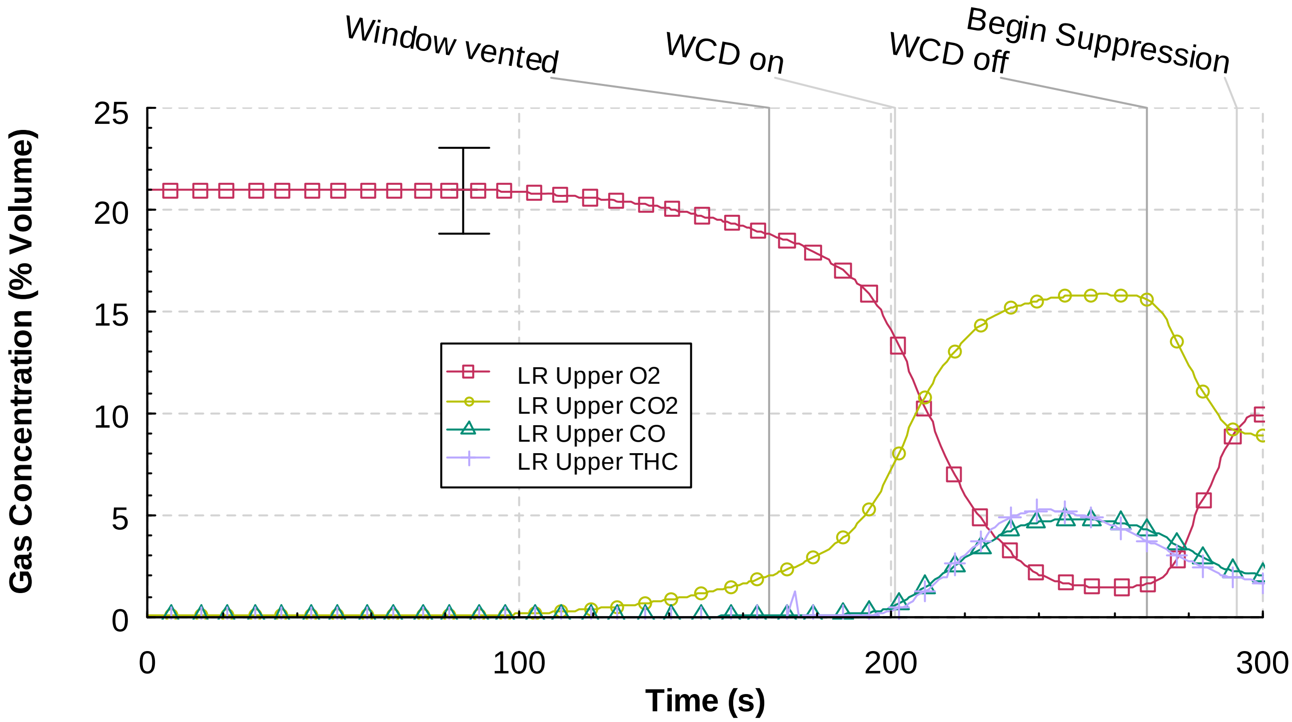

Figure 5.2.7-3. Oxygen, carbon dioxide, carbon monoxide, and total hydrocarbon percent volume versus time from the upper living (LR) room sampling location, Experiment 2.

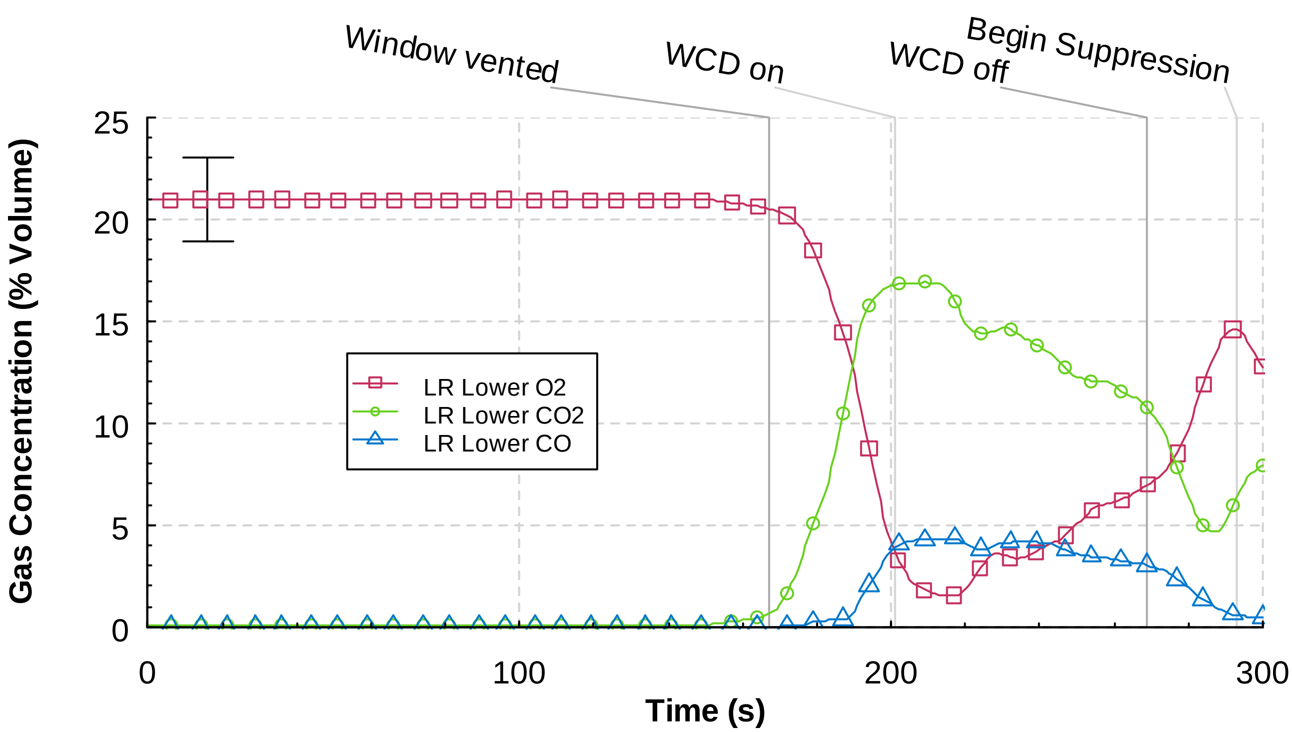

Figure 5.2.7-4. Oxygen, carbon dioxide, and carbon monoxide percent volume versus time from the lower living room (LR) sampling location, Experiment 2.

5.3 Wind Control Devices WDF 3

The third experiment in the series was similar to the second. The configuration, fuel load and fan speed were the same. The same wind control device (WCD) was deployed, but it was deployed twice as long after window failure than Experiment 2, 68 s as compared to 34 s. This allowed the assessment of a further developed wind driven condition throughout the structure. Another difference in this experiment from the previous experiment was that the WCD was removed and suppression operations were delayed for 87 s to examine the change in conditions once the wind was reintroduced.

A time line of the experiment is presented in Table 5.3-1. The results for the experiment are presented in the following sections: observations, heat release rate, temperature, heat flux, pressure, velocity, and gas concentrations. An uncertainty range marker is included in each graph.

Table 5.3-1. Experiment 3 Timeline

Time (s)	Event
0	Ignition
100	Visible smoke layer
201	Window vented mostly
203	Hot gas flow to floor in corridor IR
207	Window vented completely (bottom cleared)
266	Target room door begins to fail
268	WCD on
310	Target room door gone
325	WCD part off
330	WCD off
413	Fan off
456	Begin suppression

5.3.1 Observations

The observations are presented as a series of images captured from eight camera locations, six were video cameras and two were thermal imaging cameras. The camera positions are shown in Figure 4.1.3-1.

Figure 5.3.1-1 through Figure 5.3.1-12 present sets of eight images one from each camera position, at a given time, from the time of ignition to 456 s after ignition. Each image view is labeled. The first four views at the top of each figure show the west wall and window of the structure and then follow a path through the interior of the structure with a view of the bed room, the living room and a view (looking west) through the open door to the corridor. The second set of four views, at the bottom of each figure, provides a video view of the north east portion of the corridor and a view of the inside of the target room door. The thermal imaging cameras provide a view of the east corridor, looking north, and a view of the inside of the target room.

Figure 5.3.1-1 shows the conditions at the time of ignition. At this point, the six video views are clear and unobstructed. However, the thermal images provide limited thermal contrast because the surfaces in the view were at nearly equal temperature.

The images in Figure 5.3.1-2 were captured 60 s after ignition. The fire from the trash container began to spread to the bed. There was very little smoke being produced and a layer has yet to develop. There was also no smoke or change in thermal condition in the living room, target room or corridor at this time.

The images in Figure 5.3.1-3 were recorded at 120 s after ignition. The fire had spread to the area between the bed and the upholstered chair with a flame height of approximately 1.2 m (4 ft) above the floor. The smoke layer was approximately 0.9 m (3 ft) thick throughout the bedroom. Smoke was beginning to spread through the hallway and into the living room. No smoke and heat had made it into the corridor at 120 s. The target room appears clear of smoke.

Figure 5.3.1-4 shows the images recorded at 180 s after ignition. The fire had spread across the left side of the bed and the smoke layer in the bedroom had descended to 0.9 m (3 ft) above the floor. The smoke layer in the hallway and living room had also dropped to 0.9 m (3 ft) above the floor. Smoke and heat was flowing out of the doorway from the living room to the corridor and moving toward the vent. A small amount of smoke and heat was beginning to flow around the top of the hall door into the target room, as shown in both the video and thermal image of the target room.

Figure 5.3.1-5 shows the conditions at 208 s after ignition. The flames had touched the window at 200 s and a majority of the glass fell out of the frame. The image shows the conditions just after the window was manually cleared. Flames are seen moving across the floor level in the bedroom and the camera views in the living room, hallway and corridor are obscured by smoke. The image from the corridor IR camera shows hot gases exiting the living room, filling the doorway top to bottom and impinging on the east wall of the corridor. Heat was flowing around the entire perimeter of the hall door into the target room, as shown in the thermal image of the target room.

Figure 5.3.1-6 was captured at 222 s after ignition. Flames were flowing out of the top of the window opening. Flames can be seen in the bedroom at the floor level and flames are shown extending out through the doorway into the corridor. No flames were visible in the living room as the camera was obscured by smoke. The wood door to the target room was failing, flames were breaching the top corners of the door and a smoke layer was beginning to form in the target room.

Figure 5.3.1-7 shows the conditions at 240 s after ignition. Flames were pulsing out of the top right corner of the window opening. Flames were still visible at the floor level in the bedroom but smoke was obscuring the views in the living room and corridor. The amount of heat entering the hallway has caused the image from the corridor IR camera to deteriorate substantially. The visual image in the target room showed flames consuming both sides of the door and beginning to come under the door. The visibility at the lower layer in the target room remained good.

The images in Figure 5.3.1-8 were recorded at 266 s after ignition, just prior to the deployment of the large wind control device. All of the flames were being forced back into the window opening by the fan flow. All of the cameras from the bedroom through the corridor were completely obscured by smoke.

The thermal view of the corridor continued to show large quantities of heat but the ability to view any of the structure was lost. The target room video view continued to show flames around the top half of the target room door. The thermal view shows the outlines of the reinforcing material inside the hollow core door, as the door had increased in temperature.

At 270 s after ignition, the wind control device was deployed and in place as shown in the outside view of Figure 5.3.1-9. The interior video views were obscured by soot. The thermal view of the corridor no longer showed any hot gas flows, only a hot gas atmosphere. Conditions in the target room did not appear to have changed significantly in the 4 s since the images in Figure 5.3.1-8.

Figure 5.3.1-10 shows the conditions at 300 s after ignition, or approximately 30 s since deployment of the wind control device. The interior video views were still obscured by soot. The thermal image from the corridor was still saturated with heat but started to improve in clarity. In the target room the top of the door continued to burn and the thermal image captured the increased heat and the absence of the top half of the door. Although the top half of the door was missing a two layer environment still remained in the target room.

Figure 5.3.1-11 shows the conditions at 330 s after ignition, which was about 4 s after the curtain was removed from the window opening. There were flames visible in the bedroom from the outside camera view. The interior video views were still obscured by soot. The target room visual camera shows the smoke layer has descended toward the floor and thermal image shows the heat is mixing throughout the room.

The images in Figure 5.3.1-12 were recorded at 360 s after ignition, and 34 s after the WCD was removed. The outside view shows the bedroom was fully involved in flames with a large amount of flames pulsing out of the window opening. All of the camera views were obscured with the exception of the target room thermal view which still shows the outline of the doorway between the hallway and target room. The experiment was terminated at 380 s and the fire was suppressed.

Figure 5.3.1-1. Experiment 3, ignition.

Figure 5.3.1-2. Experiment 3, 60 s after ignition.

Figure 5.3.1-3. Experiment 3, 120 s after ignition.

Figure 5.3.1-4. Experiment 3, 180 s after ignition.

Figure 5.3.1-5. Experiment 3, window fully vented, 208 s after ignition.

Figure 5.3.1-6. Experiment 3, corridor flames, 222 s after ignition.

Figure 5.3.1-7. Experiment 3, 240 s after ignition.

Figure 5.3.1-8. Experiment 3, WCD deployed, 266 s after ignition.

Figure 5.3.1-9. Experiment 3, WCD in place, 270 s after ignition.

Figure 5.3.1-10. Experiment 3, 300 s after ignition.

Figure 5.3.1-11. Experiment 3, WCD removed, 330 s after ignition.

Figure 5.3.1-12. Experiment 3, 360 s after ignition.

5.3.2 Heat Release Rate

Figure 5.3.2-1 shows the heat release rate time history for Experiment 3. The increase in measured heat release rate is delayed because for the first 150 s after ignition no heat or combustion products generated by the fire flowed out of the structure. The measured heat release rate increased only slightly prior to the failure of the window, this may be due in part to the a 6.8 m/s to 9.1 m/s (15 mph to 20 mph) wind which was flowing over and around the structure. After the window failed, at 201 s after ignition, the increase in heat release rate is clear. The heat release rate reached a peak of approximately 18 MW, 30 s after window failure. The large WCD was deployed and in place at 268 s after ignition. This resulted in a significant decrease in heat release rate. Within 30 s after the WCD was in place the heat release rate dropped from approximately 18 MW down to approximately 2 MW. Once the WCD was removed the air flowed into the window and within seconds the visible fire in the bedroom increased until the entire room appeared fully involved. Shortly after this flames extended out of the exhaust vent stack and ignited the combustion products collected in the exhaust hood. All of the combustion products burning inside and outside the structure produced a sustained heat release rate of approximately 30 MW from 360 s to 380 s. The extreme conditions created in the laboratory forced suppression measures such as shutting down the fan and activating the safety sprinklers, therefore data was discontinued at 380 s.

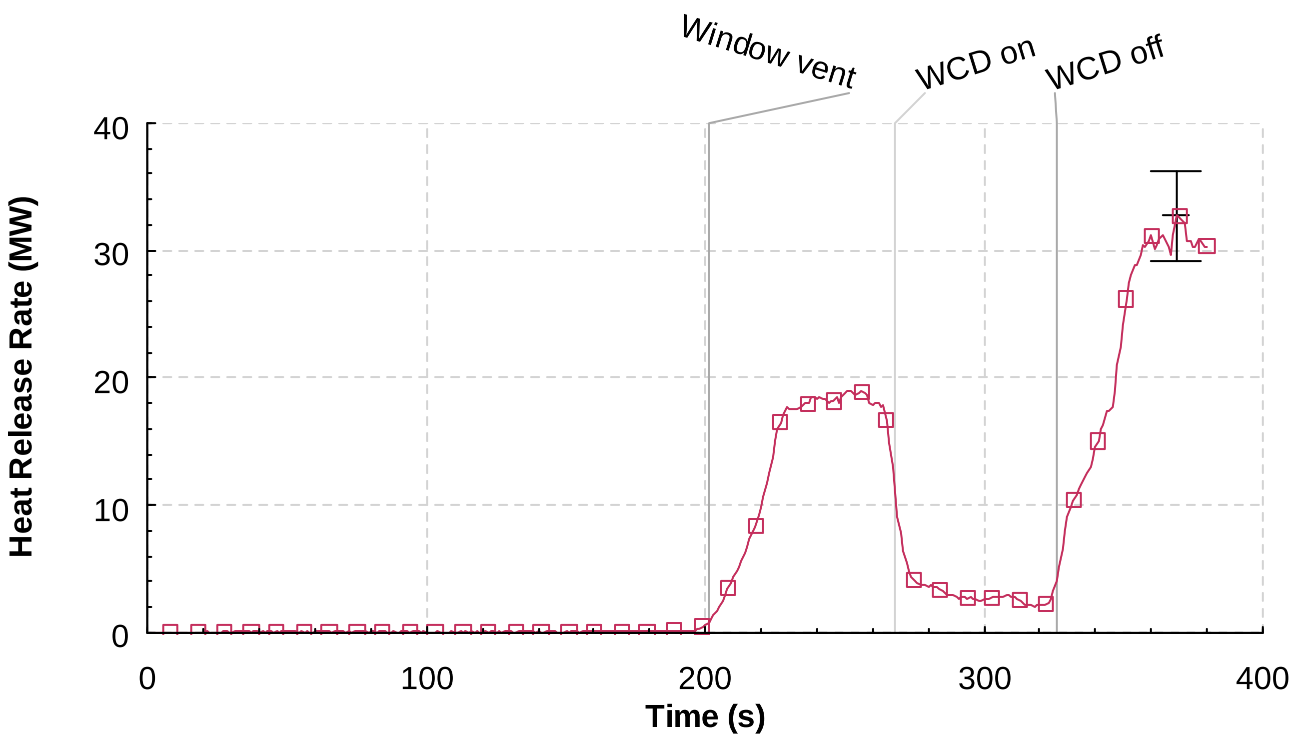

Figure 5.3.2-1. Heat release rate versus time, Experiment 3.

5.3.3 Temperatures

Figure 5.3.3-1 through Figure 5.3.3-12 provide the temperature measurements from the thermocouple arrays shown in Figure 4.1.3-1. The figures are given in order from the western most measurement point, the bed room window opening, and moving through the structure toward the east; bedroom, hall, living room, corridor, south and southwest portions of the corridor (closed end) and then to the north section of the corridor and ending with the exhaust vent. The last two temperature graphs have temperatures associated with the target room.

The three thermocouples located in the window opening, shown in Figure 5.3.3-1, provide insight into the ventilation conditions at the window. Prior to failure of the window at 201 s after ignition, there was no increase in temperature outside of the window. Once the window was vented, the temperatures increased, however the increase was small compared to Experiment 1. This is due to the cooling effect of the wind blowing air into the opening. After the WCD is deployed, the thermocouples are under the WCD and the temperatures increased. The temperatures declined substantially after the removal of the WCD because of the reintroduction of cool air from the fan. Temperatures continually recovered up until the end of the experiment as burning increased with the added oxygen.

The measurements from the thermocouple array located in the center of the bedroom are given in Figure 5.3.3-2. Prior to the window failure, the temperatures in the bedroom increased from ambient conditions to a peak of approximately 700 ºC (1292 ºF) near the ceiling. At the same time, the temperatures, 2.13 m (7.00 ft) below the ceiling, were almost 100 ºC (212 ºF). After the window vented, the wind mixed and slightly cooled the gases in the room. This condition only lasted about 10 s, then the temperatures from the ceiling down to 1.52 m (5.00 ft) below the ceiling began to increase and stratify again. Flashover conditions were reached, based on temperatures from ceiling to floor being in excess of 600 ºC (1112 ºF), at approximately 215 s after ignition and 14 s after window failure. The WCD was deployed at 268 s. Within 30 s of deployment temperatures had decreased from in excess of 800 ºC (1472 ºF) to less than 500 ºC (932 ºF). The temperatures continued to decrease until the WCD was removed. Within 20 s of WCD removal, the bedroom was fully involved in flames again, as temperatures all increased to values in excess of 800 ºC (1472 ºF).

The data from the hall thermocouple array is presented in Figure 5.3.3-3. The temperatures slowly increased as the fire in the bedroom developed. The ceiling temperature in the hallway reached approximately 400 ºC (752 ºF), while the temperature 2.13 m (7.00 ft) below the ceiling was still ambient. At 220 s, 19 s after window failure the temperatures from floor to ceiling were in excess of 800 ºC (1472 ºF). Temperatures remained above 700 ºC (1292 ºF) until the WCD was deployed at 268 s. The temperatures were uniform at 900 ºC (1652 ºF) from the floor to the ceiling just before blanket deployment and decreased to below 700 ºC (1292 ºF) in 15 s. The hallway temperatures began to increase after 280 s because the hollow core wood door was burning right next to the thermocouple array. After the WCD was removed at 326 s the temperatures steadily increased to above 1100 ºC (2012 ºF).

The data from the living room corner thermocouple array is shown in Figure 5.3.3-4. These temperatures behaved similar to those in the hallway. At 201 s, after window failure, the temperatures from floor to ceiling were in excess of 500 ºC (932 ºF) in 15 s. Temperatures remained above 600 ºC (1112 ºF) until the WCD was deployed at 268 s. The temperatures continually decreased to below 450 ºC (842 ºF) until the WCD was removed from the window. After the WCD was removed at 326 s the temperatures quickly increased to above 700 ºC (1292 ºF).

The temperatures from the center of the living room are shown in Figure 5.3.3-5 for the time history of the experiment. Again there was a dramatic temperature increase seconds after the window failure. As the hot gases were forced through the living room the temperatures elevate from 300 ºC (572 ºF) at the ceiling and ambient at the floor to over 800 ºC (1472 ºF) from floor to ceiling. The temperature becomes steady and then drop by half is less than 15 s when the WCD was deployed. Once the WCD was removed the temperatures increased back above 700 ºC (1292 ºF) in less than 15 s and remained there until the experiment was terminated.

Temperature conditions in the corridor are given in Figure 5.3.3-6 through Figure 5.3.3-9. The three thermocouple arrays located just outside the doorway from the living room all elevated very quickly after the failure of the window. Temperatures in this area all exceeded 700 ºC (1292 ºF). Temperatures were lower in the southwest corner of the corridor, or the dead end, because it was out of the flow path of the products of combustion. Once the WCD was deployed the temperatures throughout the corridor decreased to below 500 ºC (932 ºF), with the lowest temperatures in the southwest corner. The temperature 2.13 m (7 ft) below the ceiling in the southwest corner remained below 300 ºC (572 ºF) for the duration of the experiment. After the WCD was removed temperatures throughout the corridor quickly returned to their peak temperatures attained prior to WCD deployment. The most extreme temperatures were located in the path from the living room to the vent stack. Areas not in the path of the vent returned to a thermal layering condition when not in the presence of a wind driven fire, when the WCD was in place.

The temperatures at the exhaust vent are given in Figure 5.3.3-10. These thermocouples are at the same elevation located 2.44 m (8 ft) above the ceiling of the corridor. The three thermocouples are spaced 0.51 m (1.67 ft) apart along the east-west centerline of the vent. These temperatures increased from less than 100 ºC (212 ºF) to greater than 600 ºC (1112 ºF) in about 20 s following window failure. With the WCD in place these temperatures all dropped below 300 ºC (572 ºF). These lower temperatures suggest there was some mixing of fresh air in the stack with the WCD in place. Once the WCD was removed the vent temperatures peak at approximately 900 ºC (1652 ºF), higher than the peak after window failure.

The next temperature graph shows the temperatures of the target room door knobs. In Figure 5.3.3-11, the temperatures from single thermocouples, in contact with the outer surface of both the knob on the hall side of the door and the knob on the target room side of the door. The metal knob assembly was in working order and the knobs were connected by the "typical" metal rod which was also connected to the latch mechanism. The temperature of the knob on the hallway side of the door increased in temperature first as would be expected, reaching approximately 120 ºC (248 ºF) at the time that the window was vented. The temperature of the knob in the target room had not increased at that point in time. After the window vented, the hall knob temperature increased immediately, while the target room knob had a delay of approximately 30 s before it began to increase in temperature. Both temperatures peaked at approximately 900 ºC (1652 ºF) just prior to WCD deployment.

The final temperature graph displays the temperature time history for the target room (Figure 5.3.3-12). All of the temperatures remain ambient until the top of the door begins to burn through. As the door continued to burn away, hot gases were forced into the room creating thermal layering with a ceiling temperature of 450 ºC (842 ºF) and a temperature near the floor of less than 100 ºC (212 ºF). After the WCD was removed there was a large amount of mixing that took place. The air being forced in by the fan decreased the upper room temperatures and increased the lower room temperatures. Once well mixed all of the temperatures increased to above 400 ºC (752 ºF) when the experiment had to be terminated.

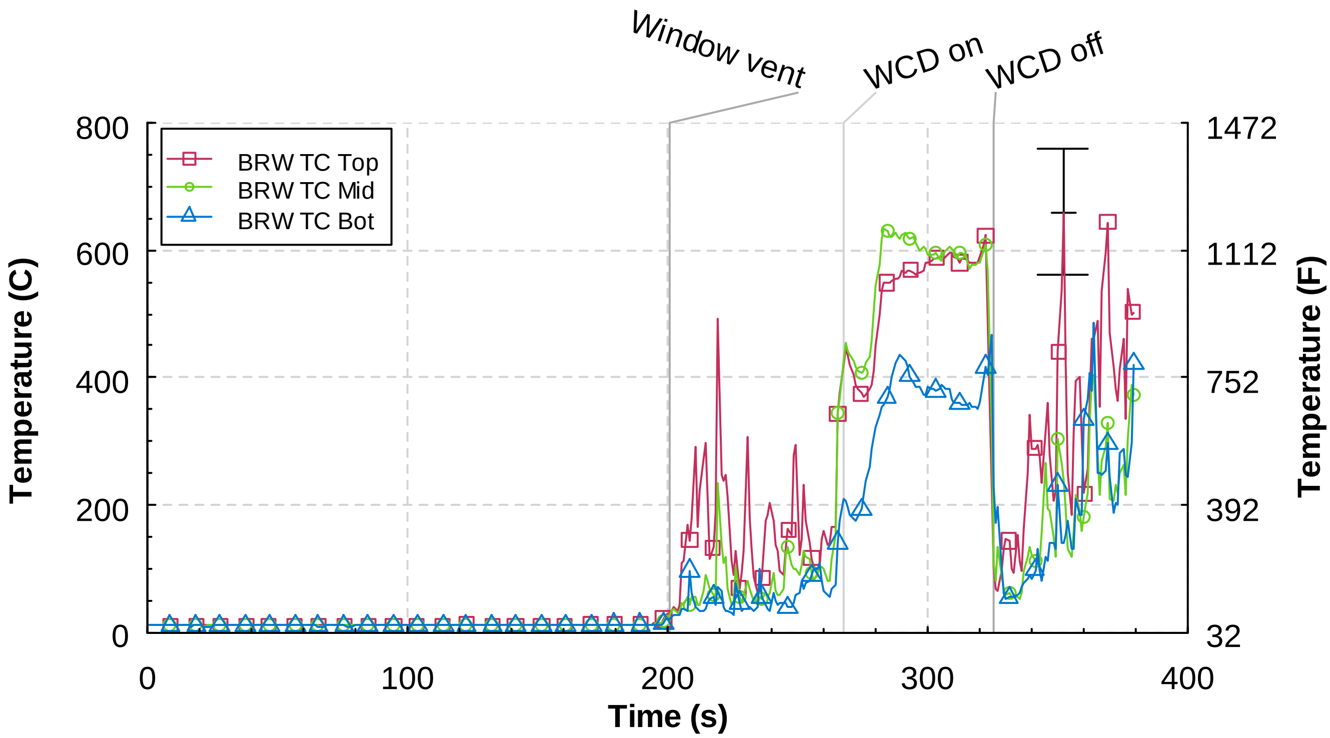

Figure 5.3.3-1. Temperature versus time from the bedroom window (BRW) thermocouple array, Experiment 3.

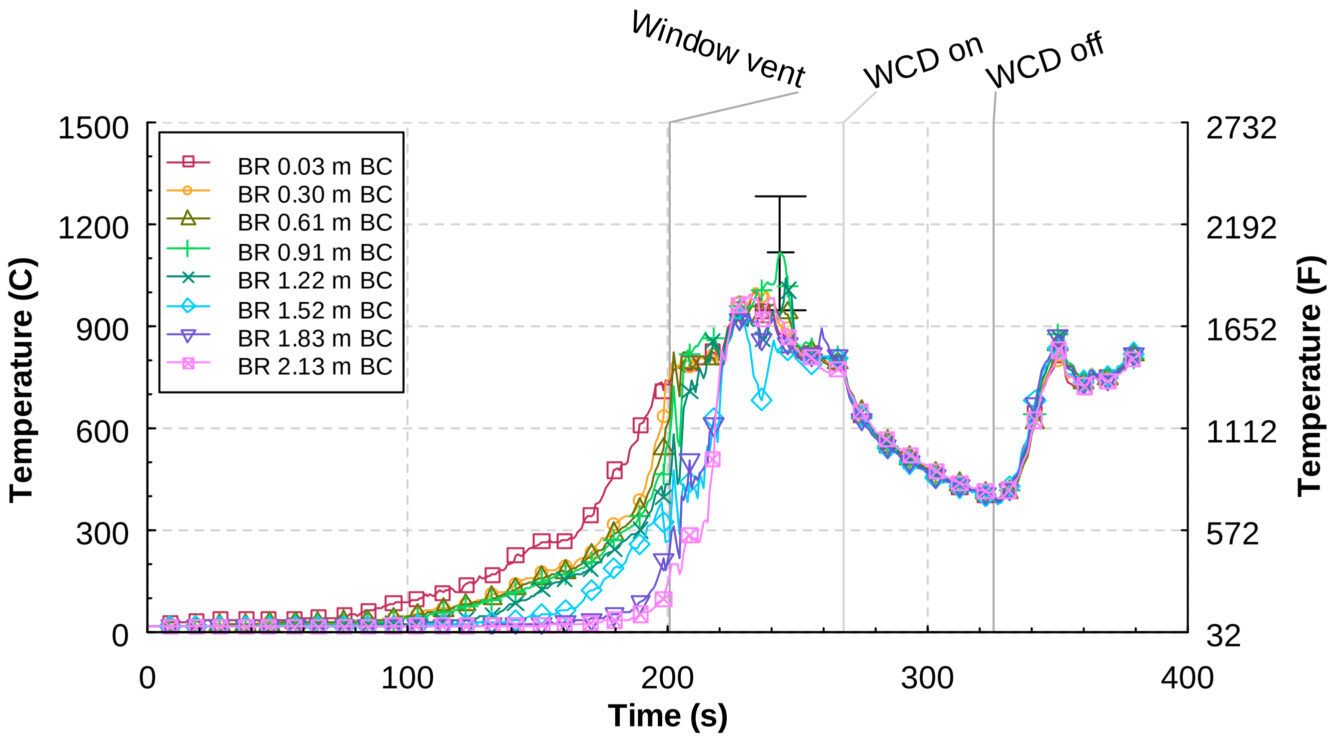

Figure 5.3.3-2. Temperature versus time from the bedroom (BR) thermocouple array, Experiment 3.

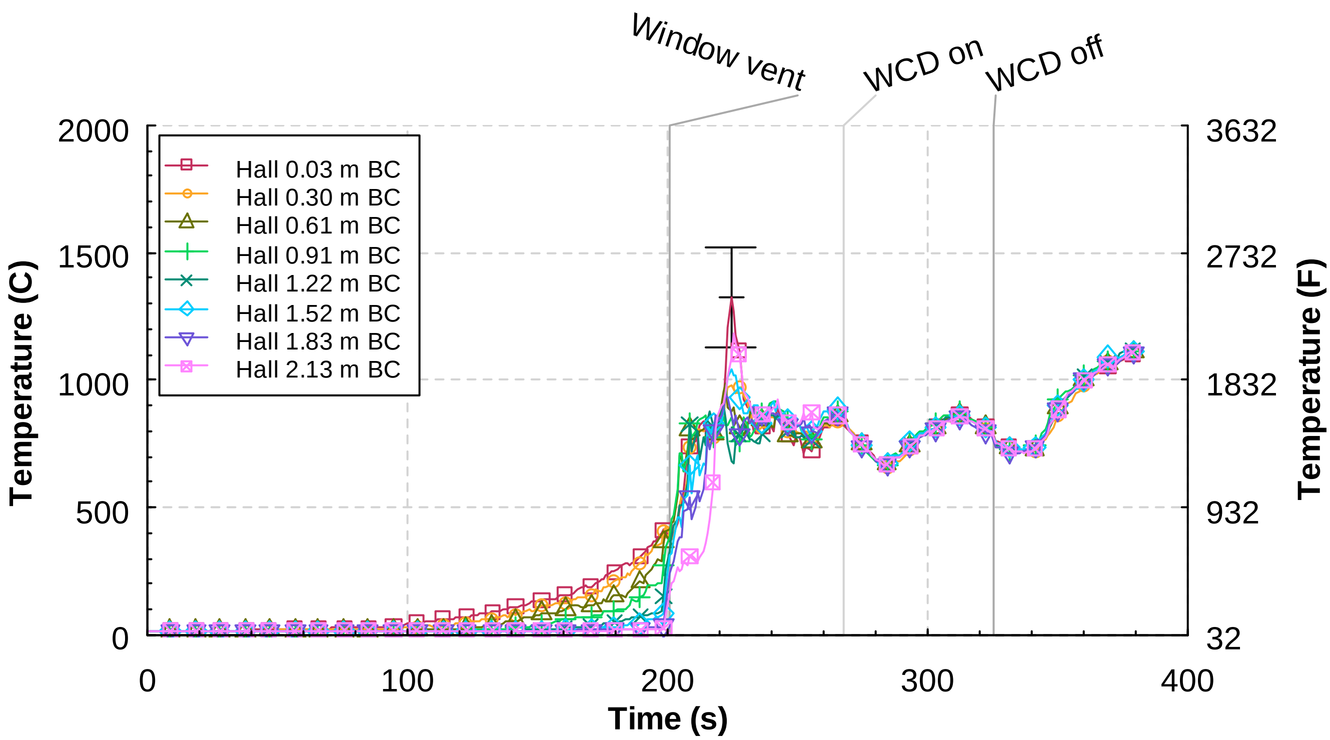

Figure 5.3.3-3. Temperature versus time from the hall thermocouple array, Experiment 3.

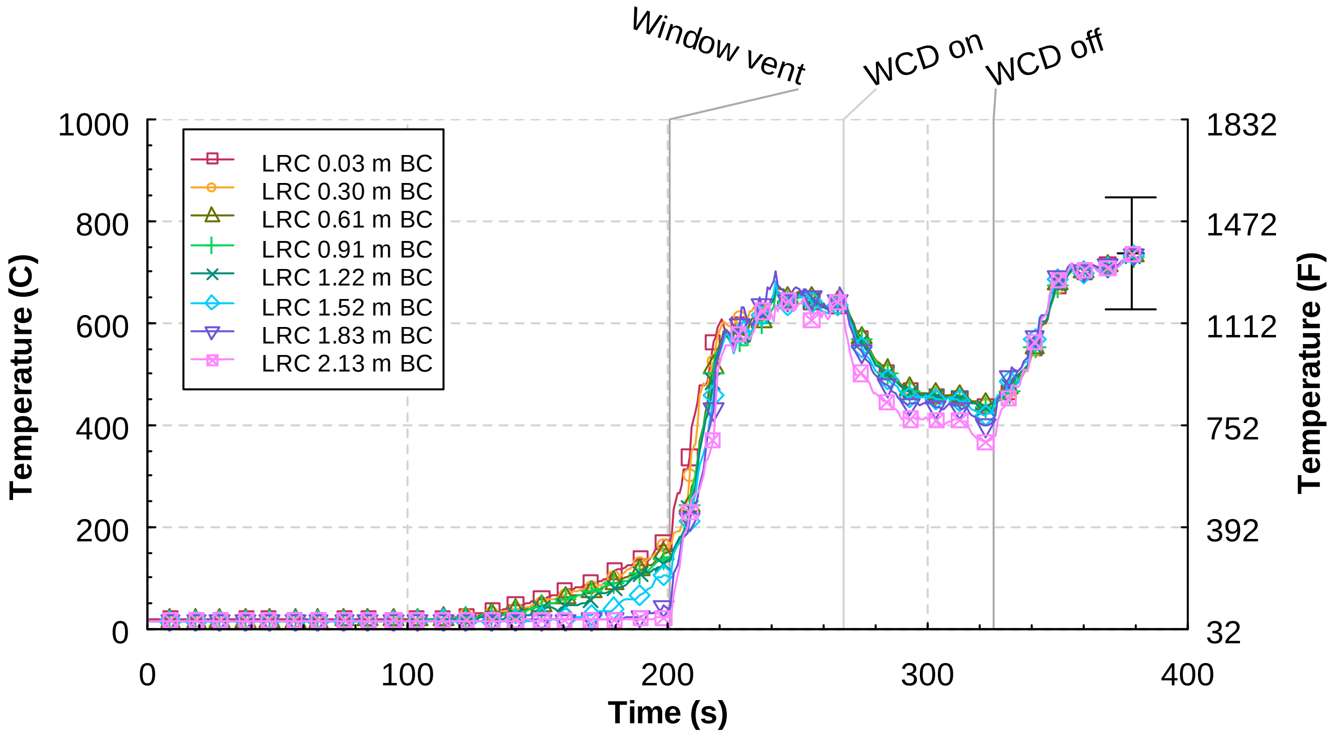

Figure 5.3.3-4. Temperature versus time from the living room corner (LRC) thermocouple array, Experiment 3.

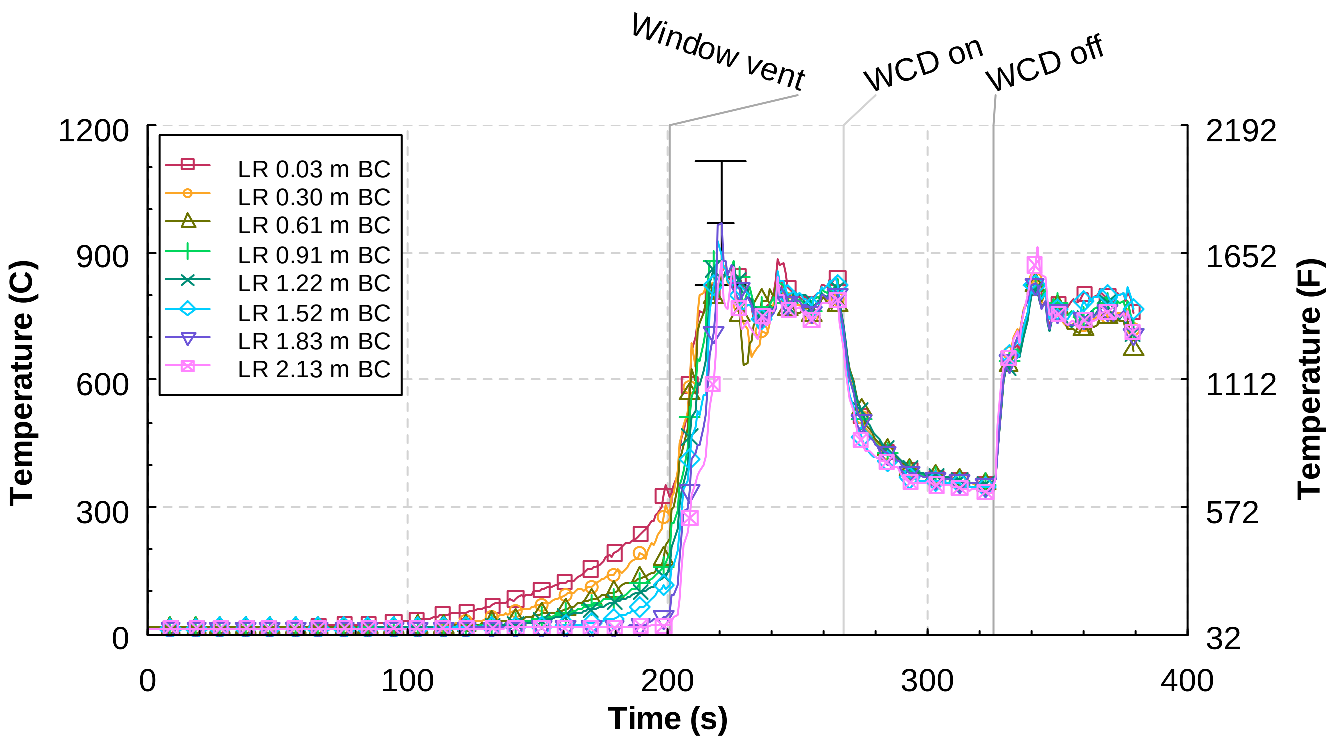

Figure 5.3.3-5. Temperature versus time from the living room (LR) thermocouple array, Experiment 3.

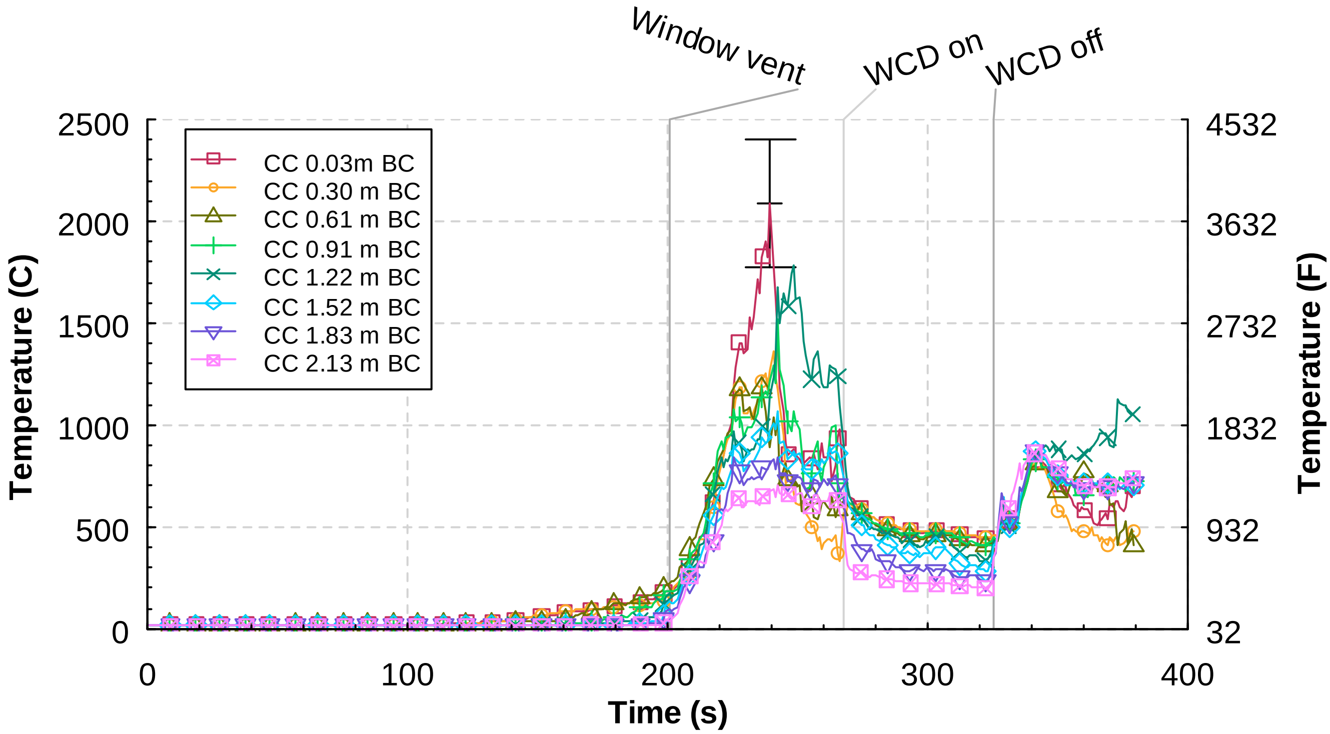

Figure 5.3.3-6. Temperature versus time from the corridor center (CC) thermocouple array, Experiment 3.

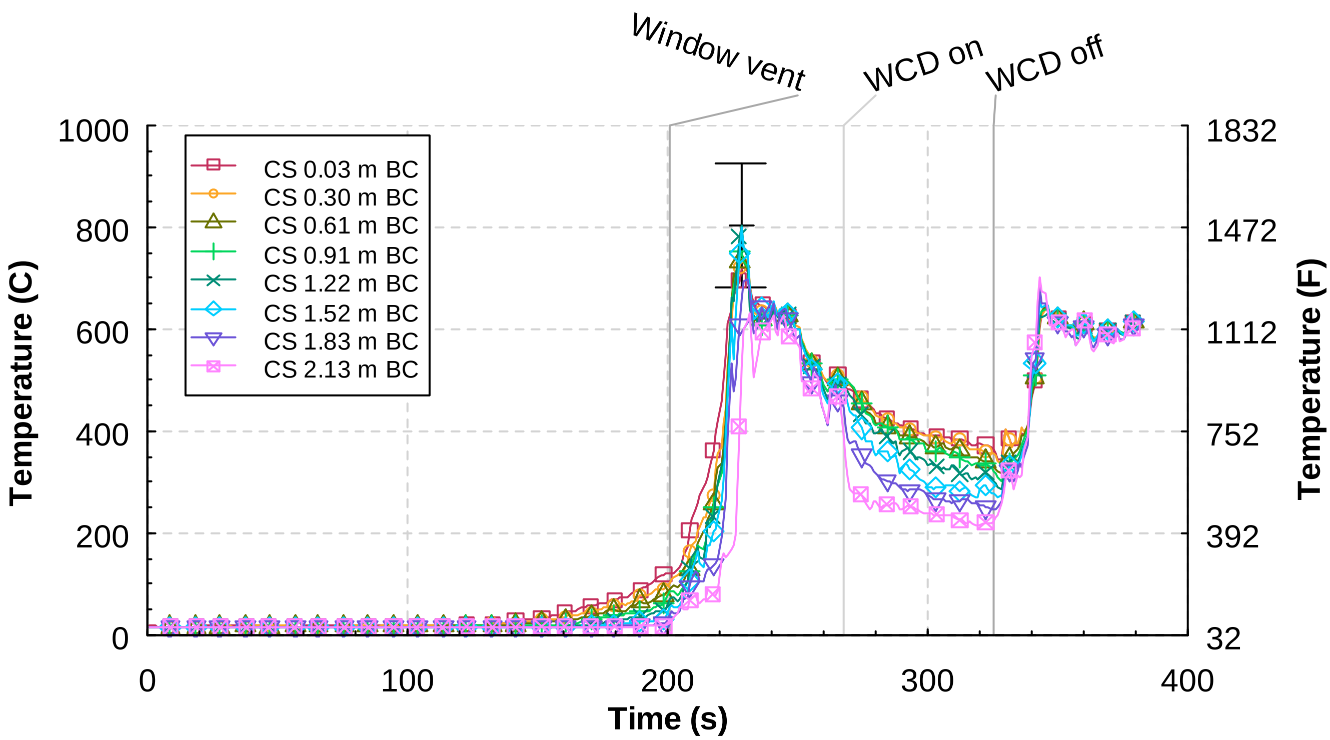

Figure 5.3.3-7. Temperature versus time from the corridor south (CS) thermocouple array, Experiment 3.

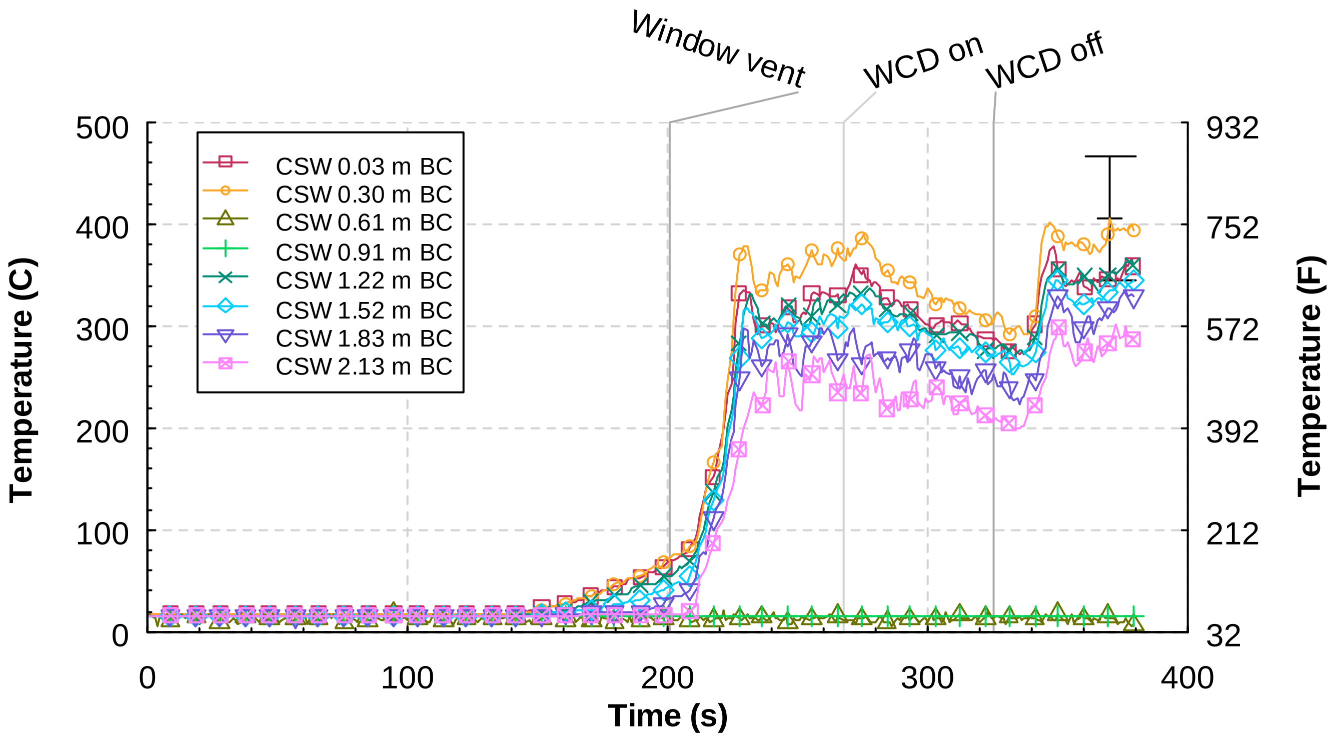

Figure 5.3.3-8. Temperature versus time from the corridor southwest (CSW) thermocouple array, Experiment 3.

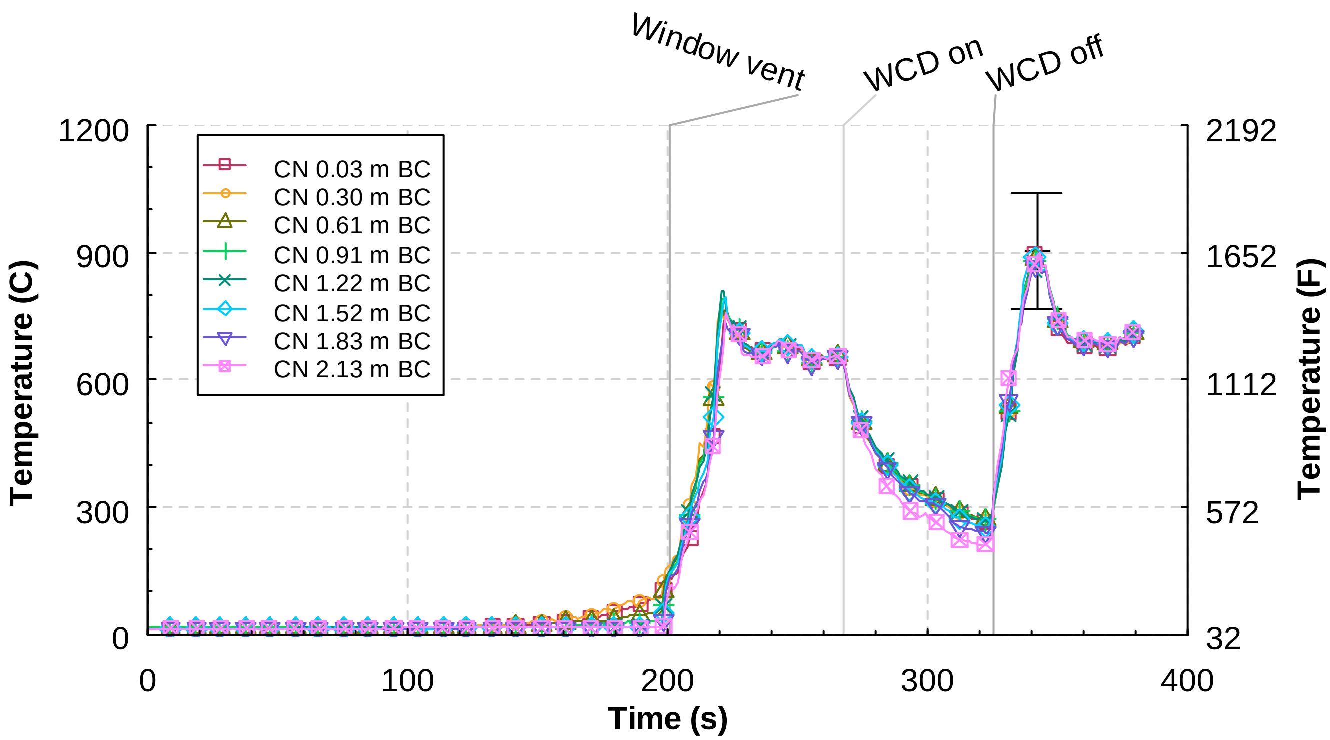

Figure 5.3.3-9. Temperature versus time from the corridor north (CN) thermocouple array, Experiment 3.

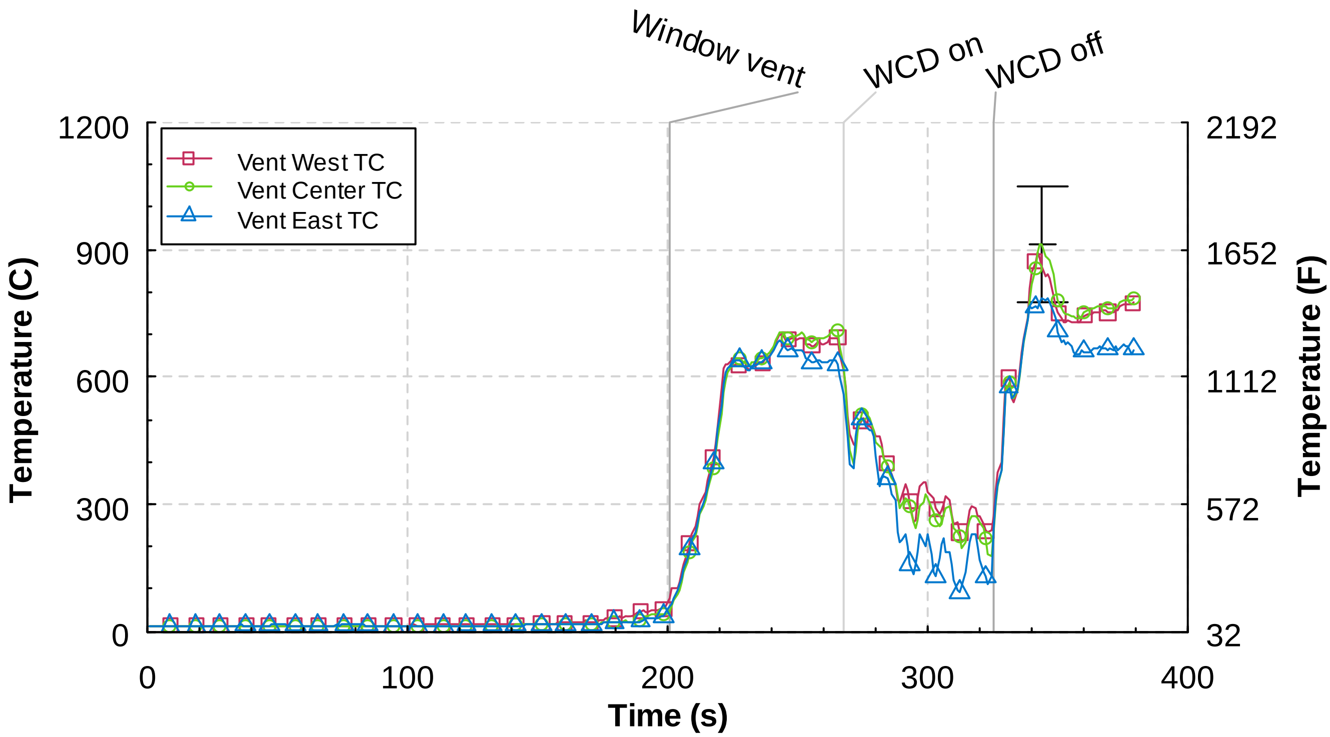

Figure 5.3.3-10. Temperature versus time from the ceiling vent thermocouple array, Experiment 3.

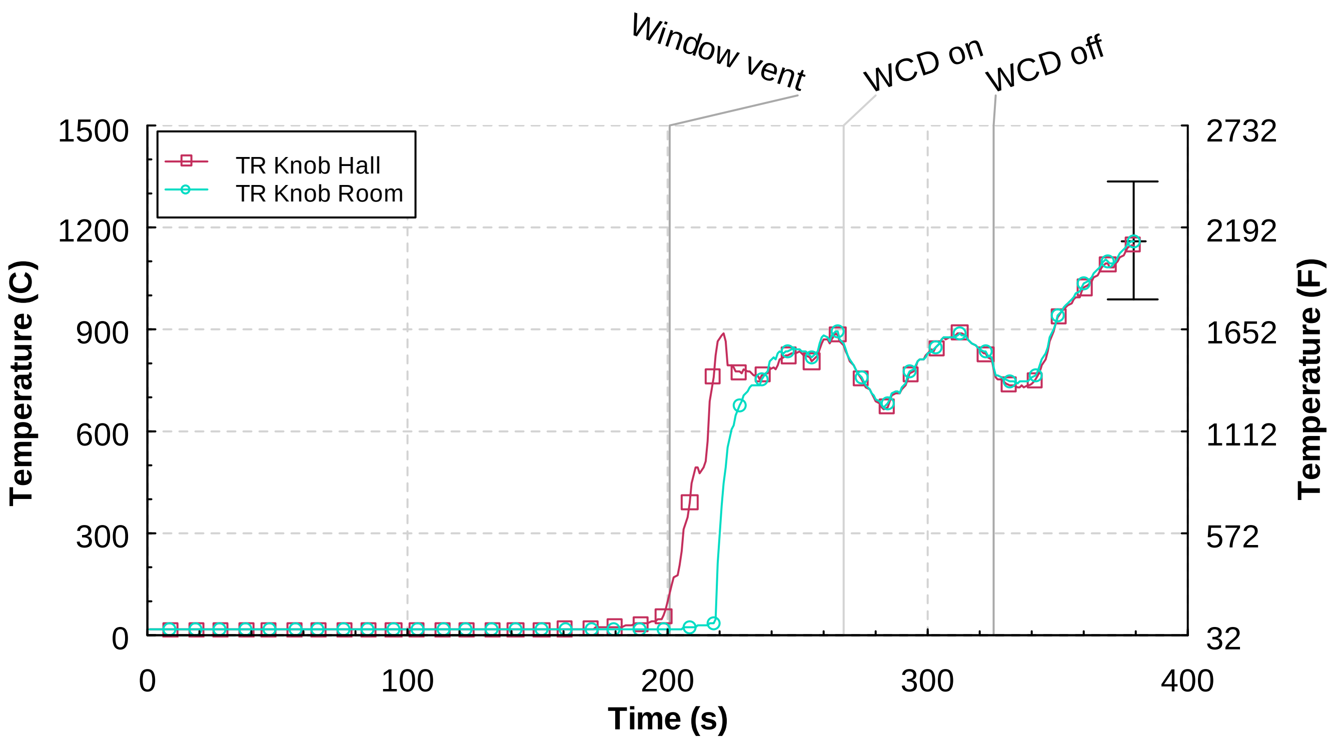

Figure 5.3.3-11. Temperature versus time from the target room (TR) door knobs, Experiment 3.

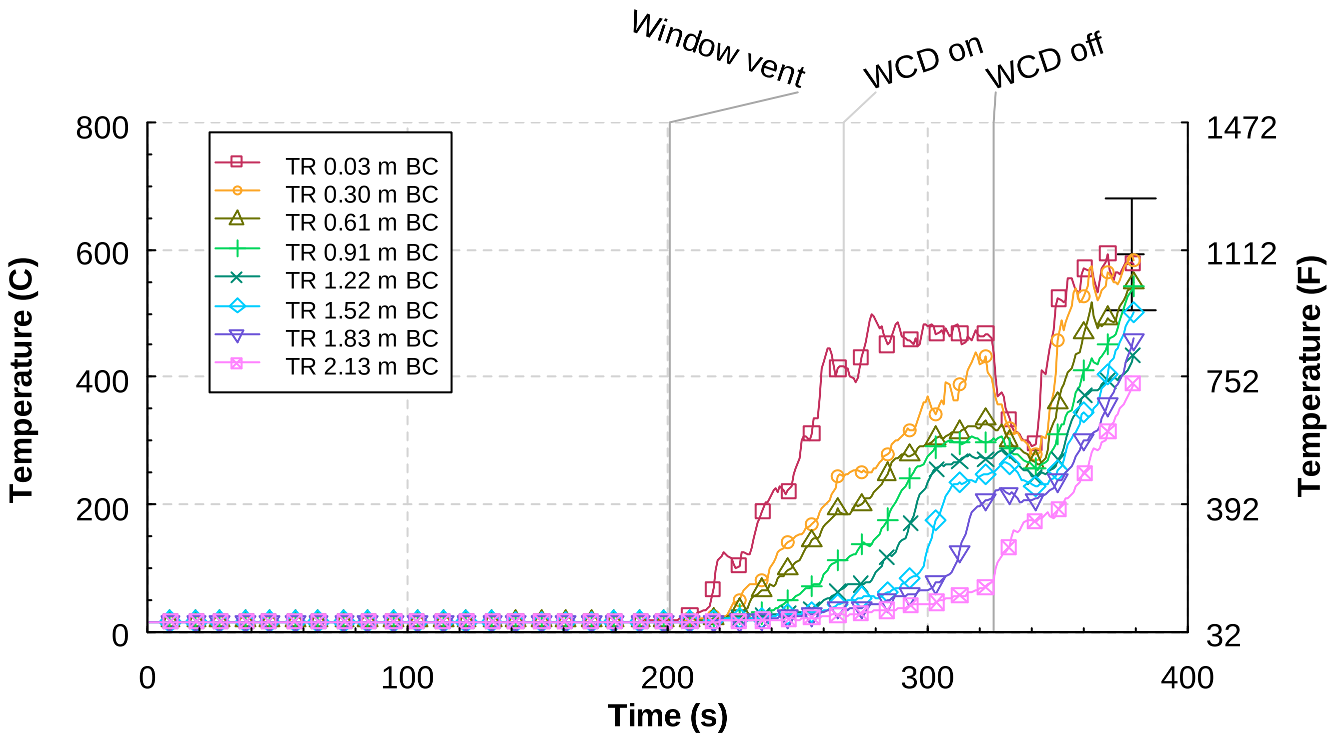

Figure 5.3.3-12. Temperature versus time from the target room (TR) thermocouple array, Experiment 3.

5.3.4 Heat Flux

The time history from all five heat flux gauges is given in Figure 5.3.4-1. The heat flux in the bedroom increased to almost 30 kW/m^2 prior to the window failure. After the window vented, the heat flux measurement in the bedroom increased to more than 160 kW/m^2 in 45 s. Every other heat flux measurement exceeded 80 kW/m^2 in the same period of time after window failure.

After the WCD was deployed the heat fluxes throughout the structure decreased to below 50 kW/m^2 in less than 10 s. They steadily decreased to approximately 30 kW/m^2 in the bedroom and living room, and 15 kW/m^2 in the corridor up to 326 s after ignition when the WCD was removed. After removal of the WCD the heat fluxes all recovered to their pre-deployment levels.

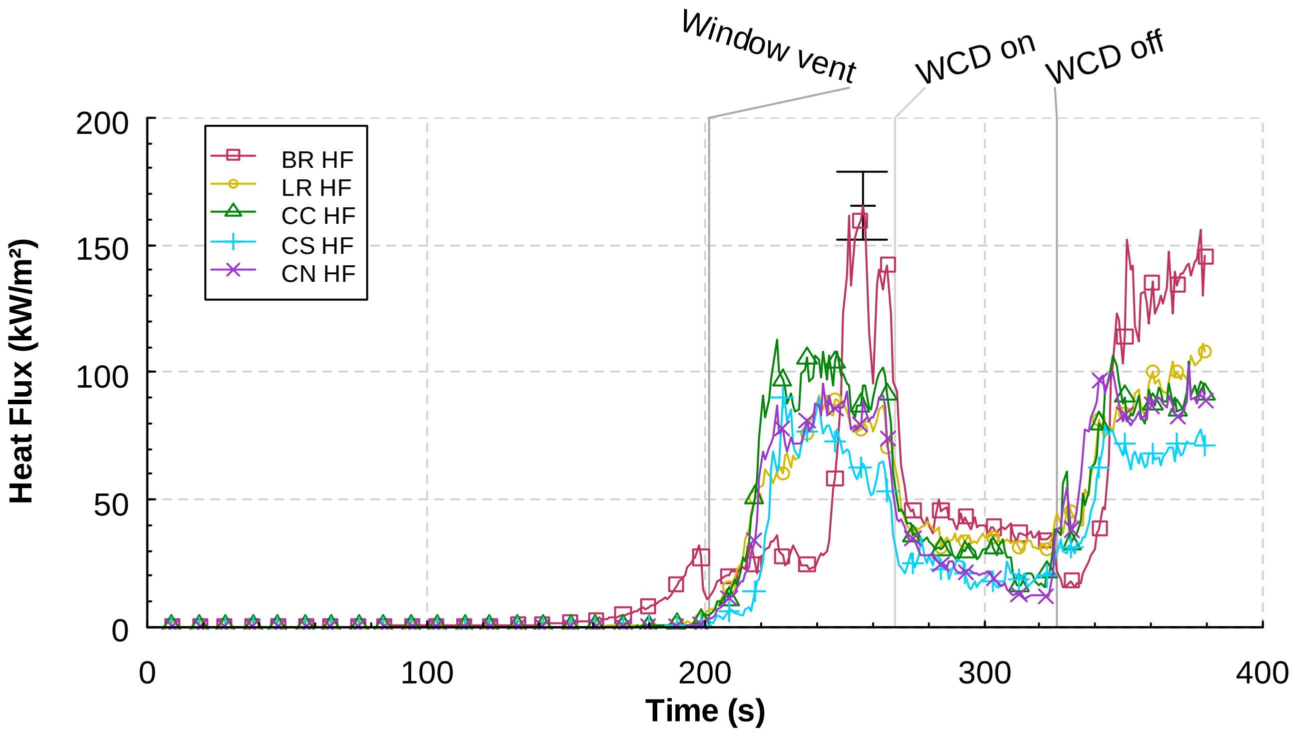

Figure 5.3.4-1. Heat flux versus time at five locations, Experiment 3.

5.3.5 Pressure

Figure 5.3.5-1 shows the pressures at the 5 measurement locations. There was a very slight pressure increase in the bedroom prior to window failure. After window failure the pressures in the structure increased and became fairly steady. The closer to the source of the simulated wind the higher the pressure was. The bedroom pressure increased to an average of 55 Pa, the hallway and living room pressure increased to approximately 35 Pa, the dead end side of the corridor increased to approximately 15 Pa and the vent side of the corridor increased to 5 Pa and then became negative as the gases were leaving through the vent above the pressure gauge.

After the WCD was deployed, all of the pressures in the structure transitioned to negative. As the pressure stabilized, the pressure in the bedroom decreased to -20 Pa and the pressures decreased to -25 Pa at the vent end of the corridor. While all of the pressures were negative the gases were still able to flow from a higher pressure (bedroom) to a lower pressure (corridor vent). The magnitude of the negative pressure was created by the flow of hot gases out of the structure and the lack of available make-up air, creating a vacuum. When the WCD was removed and the fire redeveloped, the pressures returned to the same magnitude and order that they were prior to WCD deployment.

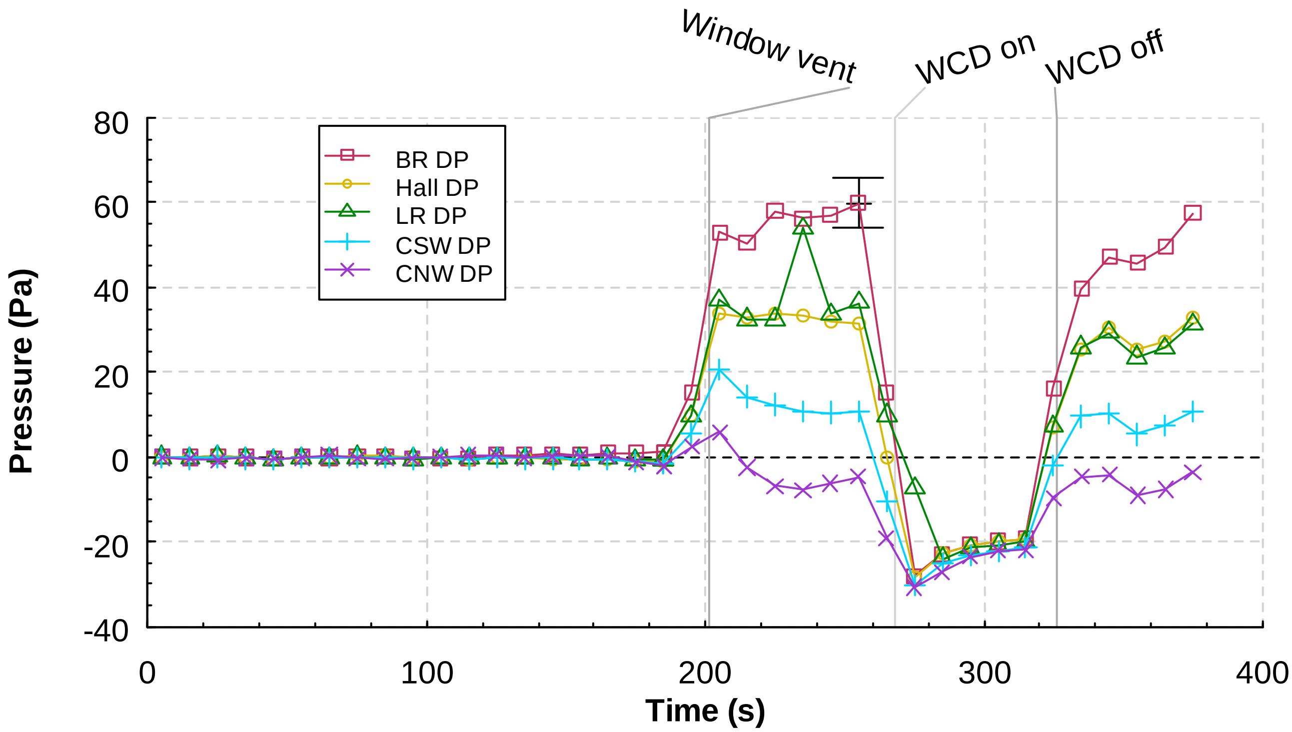

Figure 5.3.5-1. Pressure versus time at five locations, Experiment 3.

5.3.6 Velocities

Figure 5.3.6-1 provides the velocity measurements from the bi-directional probes that are located outside of the structure, 60 mm to the west of the window. The back face of the probe was 60 mm (0.20 ft) in front of the window glass, as a result there is no measured velocity until after the window began to vent. The window was completely vented at 201 s after ignition as shown on the graph timeline. The positive velocities were flowing into the window. There was a fluctuation of velocities at the window as the hot gases were trying to exit the window opening while the simulated wind was forcing the gases back into the window. The average velocities shown in the graph indicate that the bulk flow was into the window at a magnitude of approximately 2 m/s to 3 m/s. After the WCD was deployed the reading are not reliable as the WCD was pushed up against all of the probes.

Figure 5.3.6-2 shows the velocities at the hall array position. On this graph, the positive direction is from west to east. The probe located 0.3 m (1 ft) below the ceiling captures the velocity of the ceiling jet as it moved down the hall away from the bedroom and peaked at approximately 3.0 m/s (6.7 mph) prior to window failure. After window failure the velocity increases to above 6 m/s at the top probe and 8 m/s to 10 m/s at the middle and bottom measurement locations. The top probe read lower because of the impact of the size of the doorway. The lintel, which extended 0.4 m (1.3 ft) below the ceiling, slowed the flow or caused turbulence which slowed the flow.

Figure 5.3.6-3 displays the velocities from the south corridor position. The positive direction is from north to south. This was the closed end side of the corridor, so there was no steady flow through this area. There was a lot of recirculation and changes in the magnitude of the velocity. Flows ranged from

-2 m/s to 3 m/s while the wind was flowing through the structure. With the WCD in place, the flow became steady between 0 m/s at the bottom probe and 2 m/s at the top probe, toward the vent.

The velocities from the north corridor position are shown in Figure 5.3.6-4. The positive flow direction for this location is from south to north. Prior to window failure, the ceiling jet/hot gas layer velocities reached a peak of approximately 0.6 m/s (1.4 mph) at 0.3 m (1 ft) below the ceiling. After the window vented the velocities increased to a peak of approximately 7 m/s (15.7 mph) and a range of 4 m/s to 7 m/s. The velocities decreased to a range of 1 m/s to 2 m/s after WCD deployment.

The measurements from the bi-directional probes installed in the exhaust vent, 2.44 m (8.0 ft) above the ceiling are given in Figure 5.3.6-5. The flow direction up and out of the structure is positive in the figure. Prior to the window being vented the peak flow velocity is less than 2 m/s (4.5 mph). After the window was vented, the velocities at all three probes were similar and flowing out of the structure at a speed of approximately 9 m/s (20.1 mph). After WCD deployment the velocities decreased to 1 m/s to 3 m/s but were still unidirectional out of the structure. Once the WCD was removed the flows increased back to above 10 m/s (22.4 mph) for the duration of the experiment.

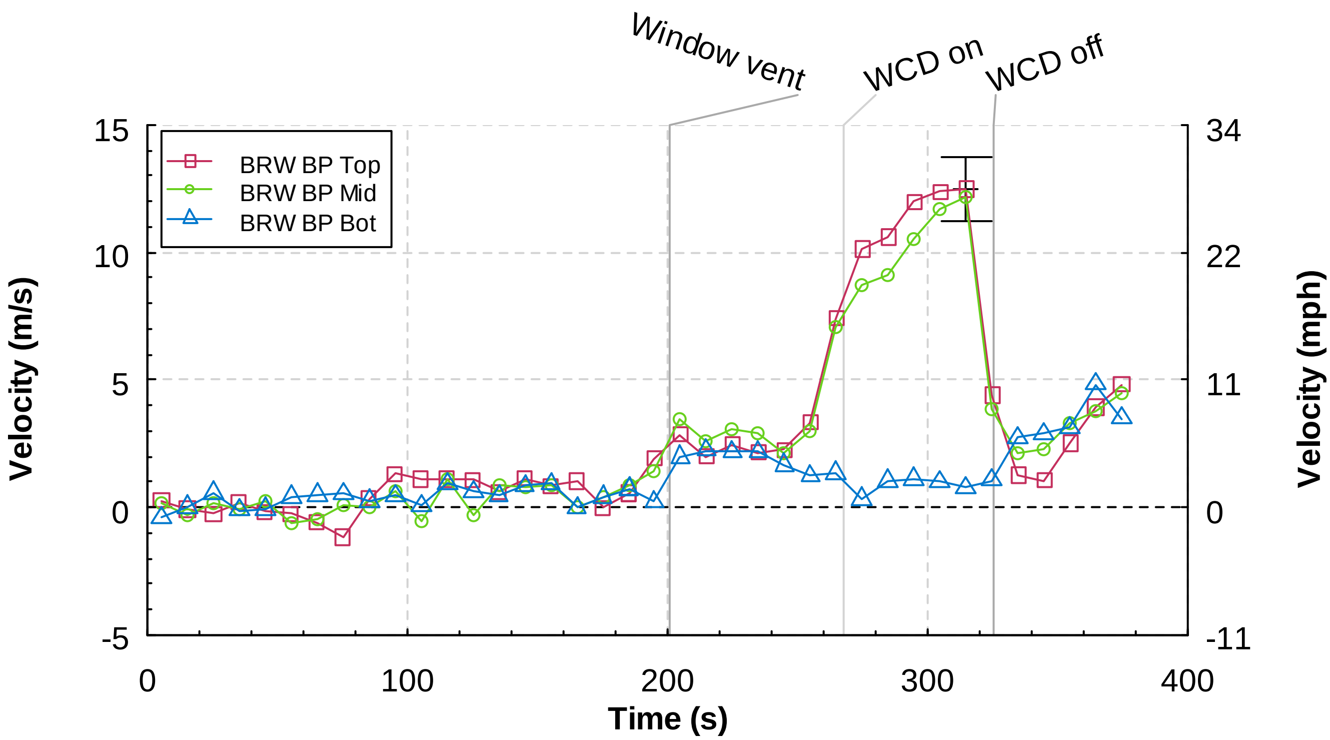

Figure 5.3.6-1. Velocity versus time from the bedroom window (BRW) bi-directional probe array, Experiment 3.

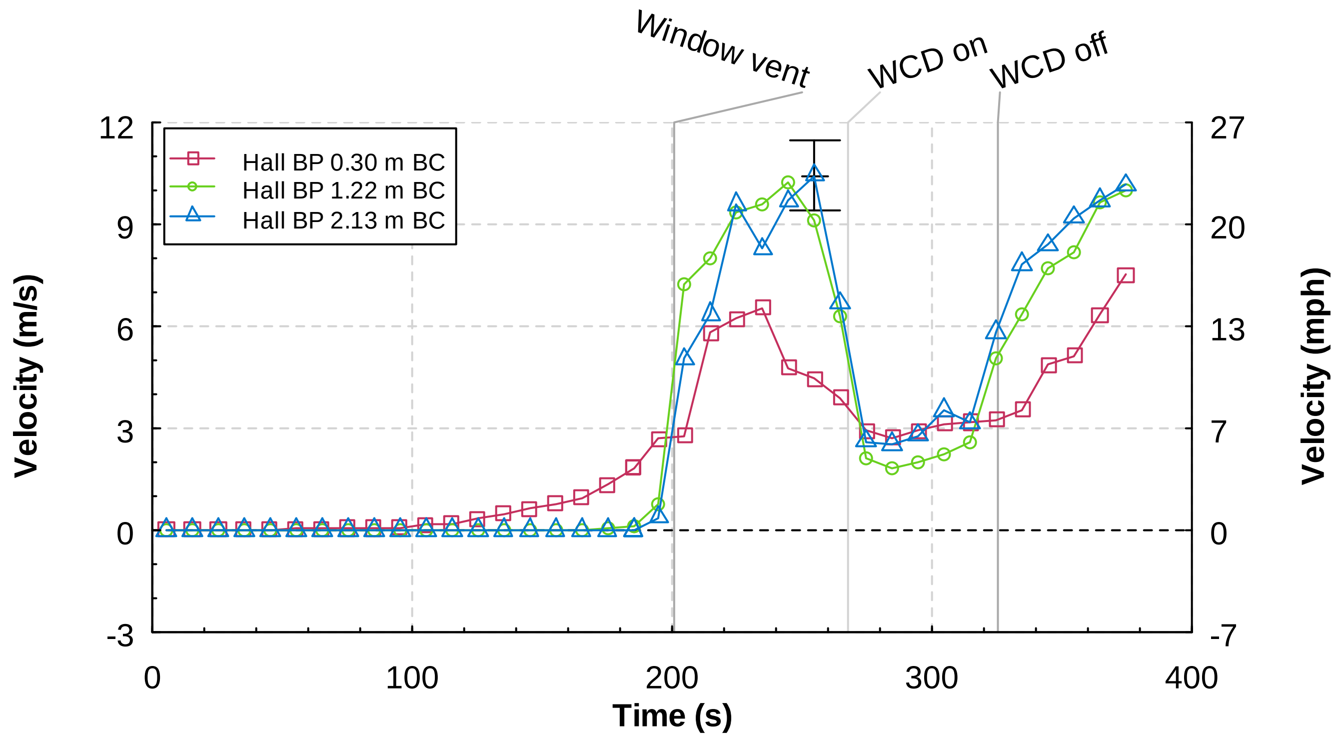

Figure 5.3.6-2. Velocity versus time from the hall bi-directional probe array, Experiment 3.

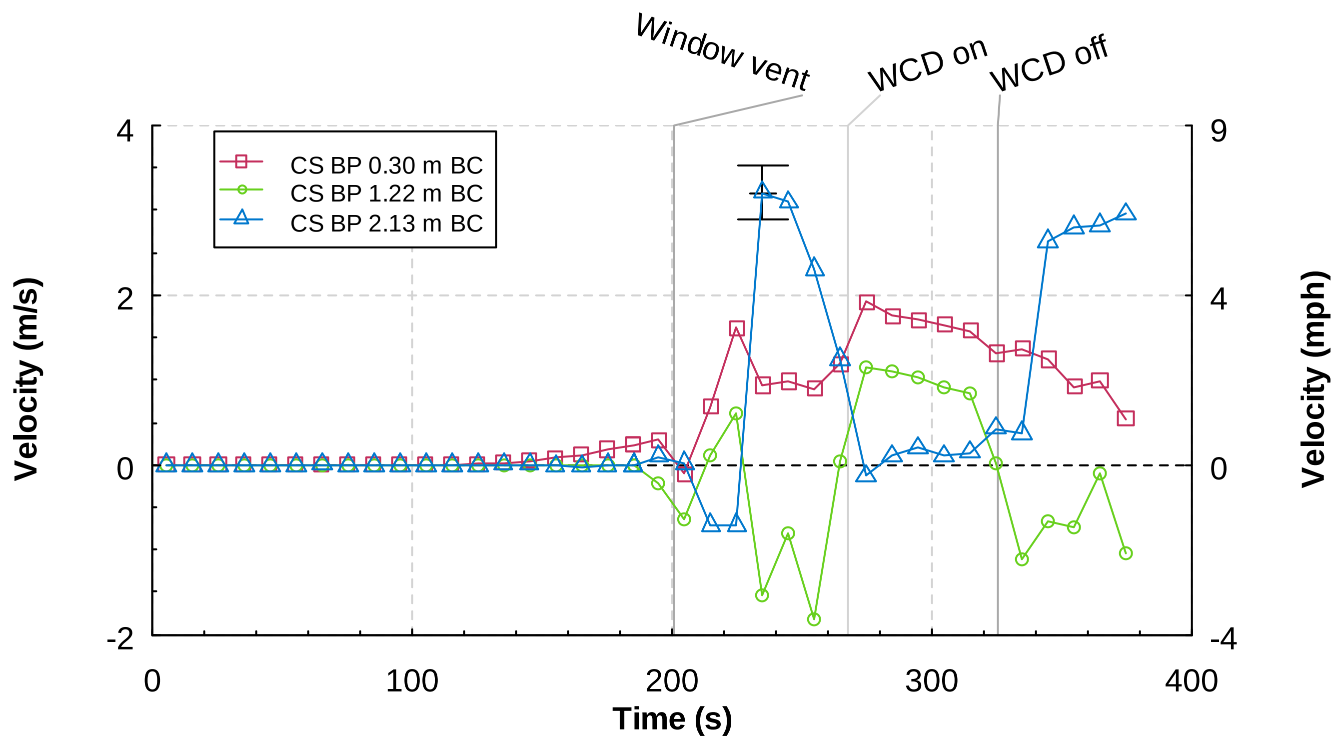

Figure 5.3.6-3. Velocity versus time from the corridor south (CS) bi-directional probe array, Experiment 3.

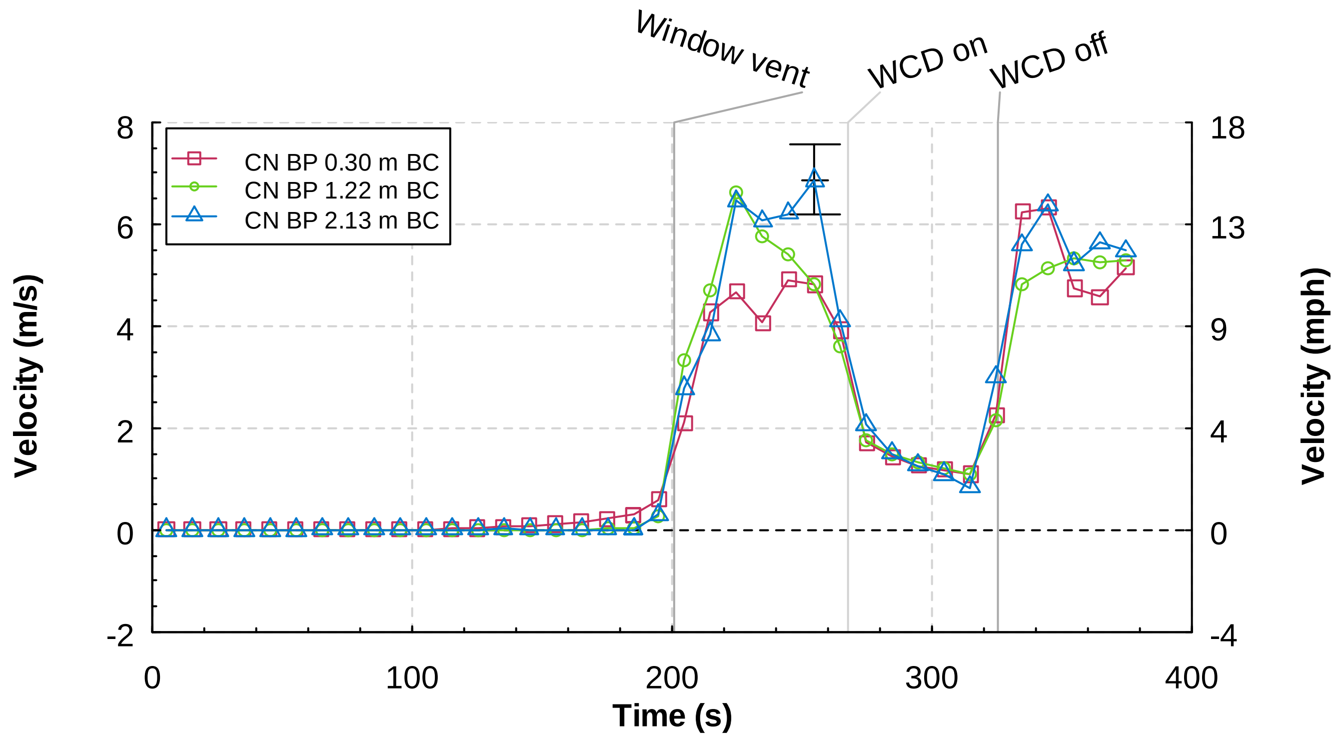

Figure 5.3.6-4. Velocity versus time from the corridor north (CN) bi-directional probe array, Experiment 3.

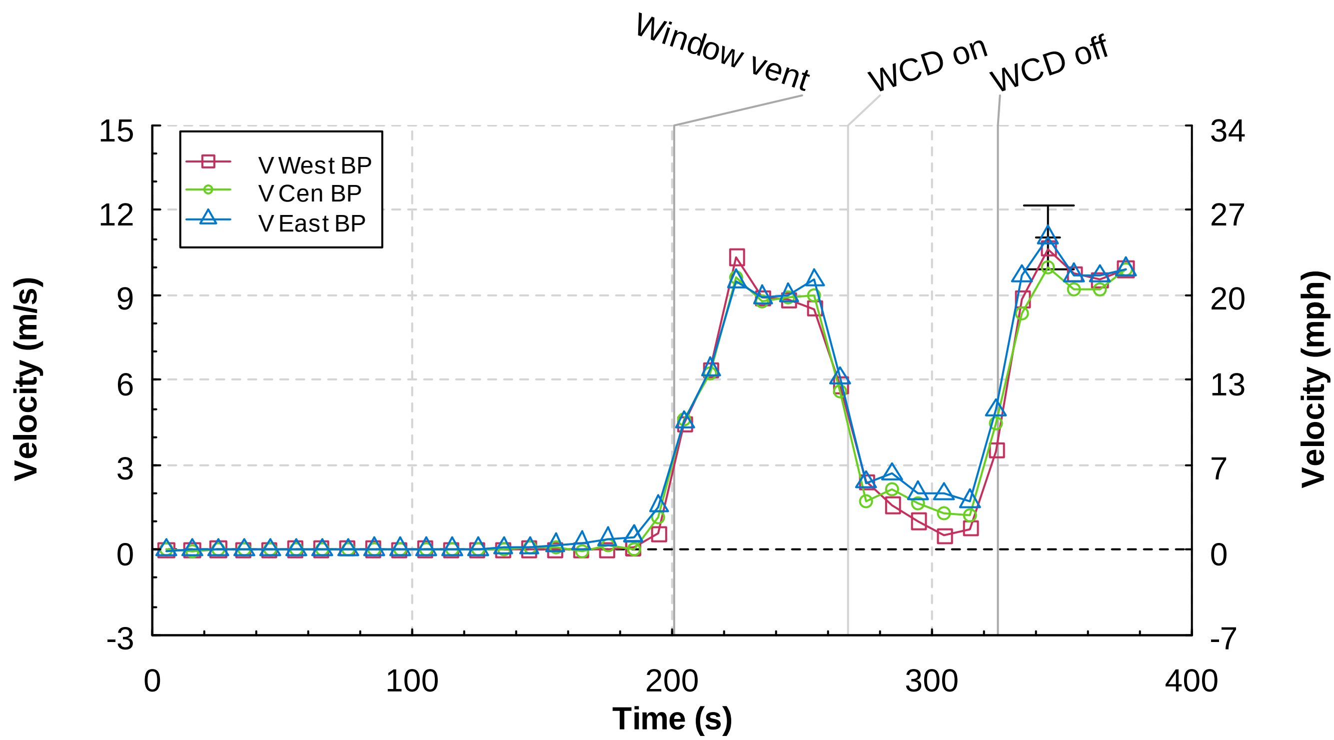

Figure 5.3.6-5. Velocity versus time from the ceiling vent (V) bi-directional probe array, Experiment 3.

5.3.7 Gas Concentrations

Figure 5.3.7-1 and Figure 5.3.7-2 show the gas concentration measurements made in the bedroom. At the start of the experiment, the oxygen is approximately 21 % and the combustion products are near zero. As the fire grew, the oxygen in the upper layer, Figure 5.3.7-1, slowly decreased to approximately 18 % within 200 s after ignition. During the same period, the carbon dioxide increased noticeably. After window failure the oxygen continued to decline to 7 % before the WCD was deployed. At this same time the carbon dioxide had increased to 12 % and the carbon monoxide to 2 %. With the WCD in place the oxygen dropped to 1 %, carbon dioxide to 16 % and carbon monoxide to 6 %

The gas concentrations in the lower portion of the bedroom began to change at approximately 190 s, as the hot gas layer developed and extended down 1.83 m (6.0 ft) from the ceiling to interact with the sampling probe. After the window vented at 201 s, the fresh air came in through the window and mixed with the lower portion of the hot gas layer, which significantly delayed the decrease of oxygen and increase of carbon dioxide and carbon monoxide for about 40 s. After this mixing, the oxygen quickly dropped to below 1 %, the CO_2 increased to 17 % and the CO increased to 8 %. After the WCD was removed the oxygen increased from 1 % to 18 % and back down to 3 % in 40 s. Similar trends took place in the CO_2 and CO readings as air was introduced and consumed very rapidly.

Figure 5.3.7-3 and Figure 5.3.7-4 provide the measurements from the upper and lower gas sampling probes, respectively, in the living room. The magnitudes and trends of the living room gas concentrations are very similar to those of the bedroom. One main difference is a smaller impact when air was introduced by either the failing of the window or the removal of the WCD. Much of the oxygen entering the window was consumed by the fire in the bedroom and it did not make it to the living room. As an example, the bedroom lower oxygen concentration increased from 1 % to 18 % when the WCD was removed. The same probe in the living room increased from 1 % to 3 % before declining again.

Figure 5.3.7-3 also includes the total hydrocarbon readings from the upper gas sampling probe in the living room. The total hydrocarbon readings begin to increase at about the same time as the CO readings but continue to increase to a peak of 11 % with the WCD in place and the oxygen concentration at a minimum. The concentration decreases slightly with the WCD in place which suggests that there was some combustion taking place in the living room.

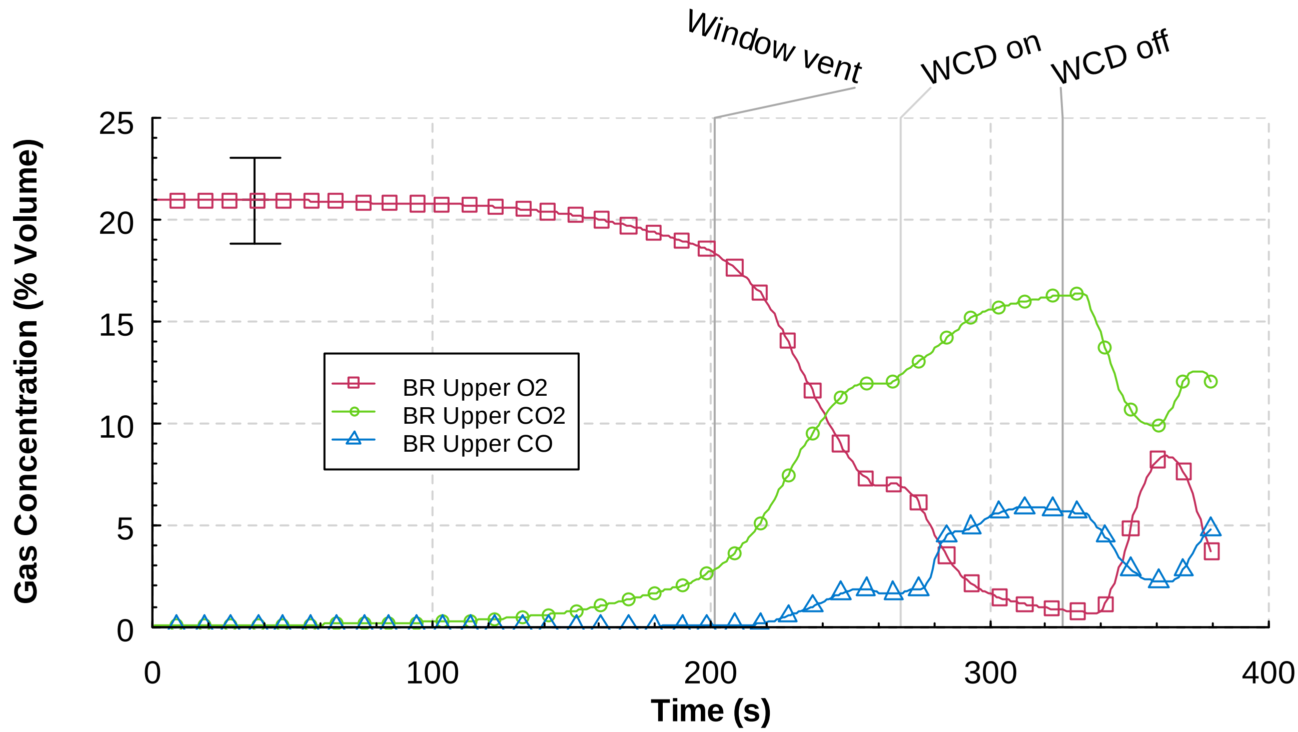

Figure 5.3.7-1. Oxygen, carbon dioxide, carbon monoxide, and total hydrocarbon percent volume versus time from the upper bedroom (BR) sampling location, Experiment 3.

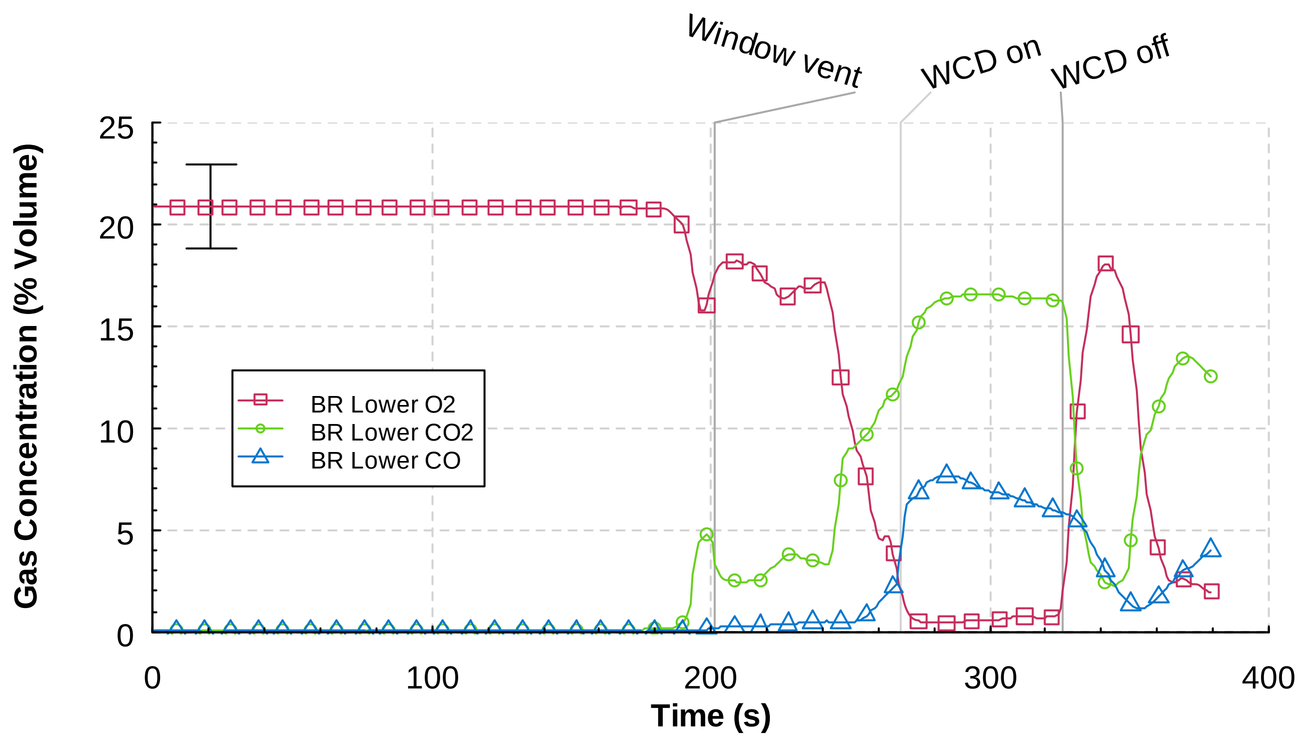

Figure 5.3.7-2. Oxygen, carbon dioxide, and carbon monoxide percent volume versus time from the lower bedroom (BR) sampling location, Experiment 3.

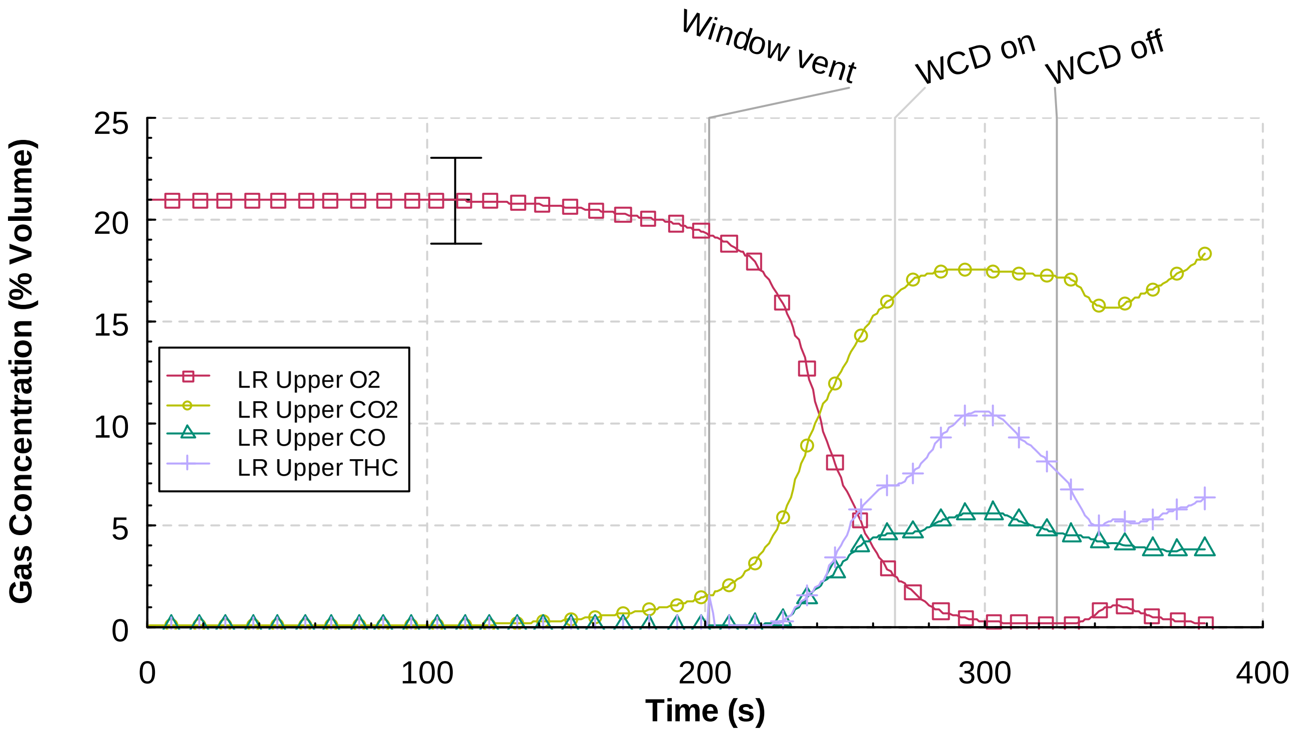

Figure 5.3.7-3. Oxygen, carbon dioxide, carbon monoxide, and total hydrocarbon percent volume versus time from the upper living (LR) room sampling location, Experiment 3.

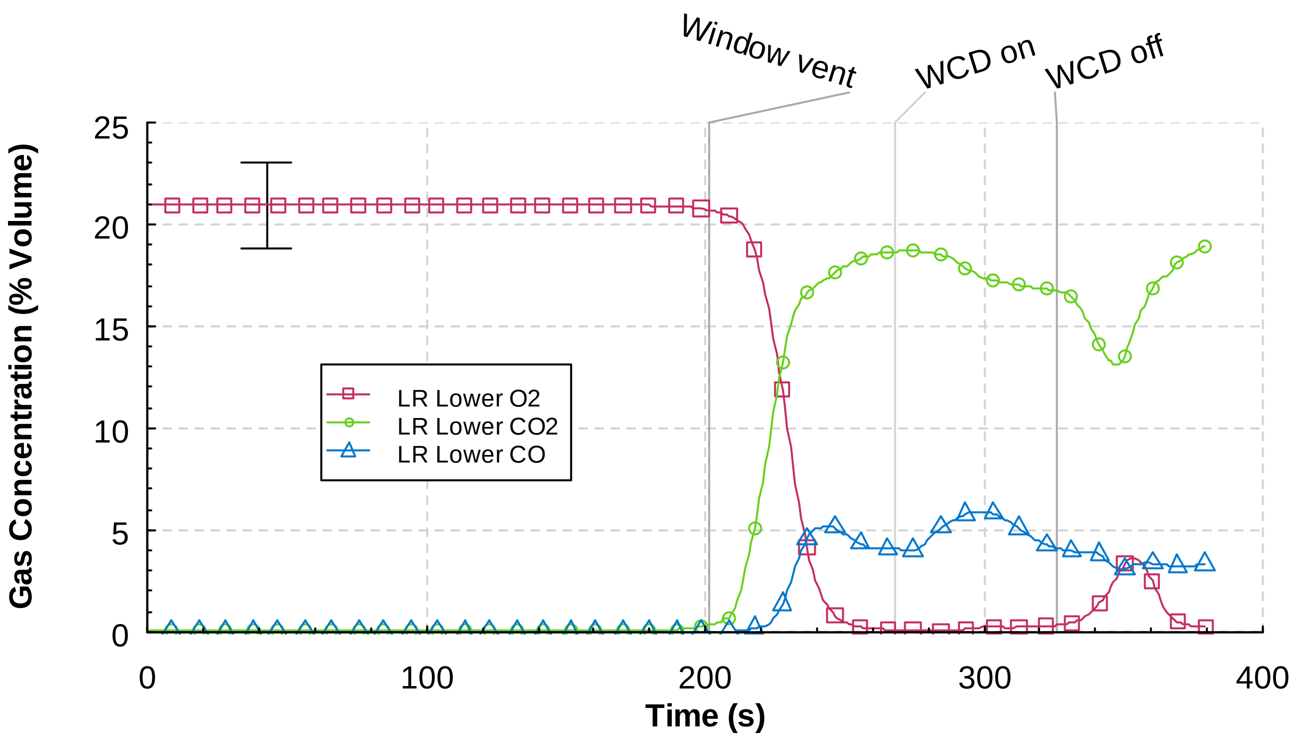

Figure 5.3.7-4. Oxygen, carbon dioxide, and carbon monoxide percent volume versus time from the lower living room (LR) sampling location, Experiment 3.

5.4 Wind Control Devices with suppression WDF 4

The fourth experiment in the series was conducted to examine the impact of wind on the structure fire, quantify the impact of the small WCD, and quantify the impact of a relative small water spray 1.9 l/s (30 gpm) injected from under the WCD into the window opening. The small WCD measured 1.8 m (6.0 ft) by 2.4 m (8.0 ft). In the wind control experiments, as described in Section 4.3.2, this wind control device reduced the velocity in the structure to zero. Another difference in this experiment is the use of a steel target room door. The experimental preparations were made as described in Section 5.

In this experiment, natural wind from outside the Large Fire Facility was augmenting the air flow that was produced by the fan. The natural wind speed without the fan was approximately 1.8 m/s (4.0 mph) at the window opening. The fan speed used in this experiment was 2500 RPM, which resulted in a 6.7 m/s to 8.9 m/s (15 mph to 20 mph) wind speed at the window opening. A trash container fuel package was ignited remotely with an electric match to start the experiment at Time = 0 s.

A time line of the experiment is presented in Table 5.4-1. The results for the experiment are presented in the following sections: observations, heat release rate, temperature, heat flux, pressure, velocity, and gas concentrations. An uncertainty range marker is included in each graph.

Table 5.4-1. Experiment 4 Timeline

Time (s)	Event
0	Ignition
110	Visible smoke layer
206	Window vented
209	Hot gas flow to floor in corridor IR
269	WCD on
332	Window sprinkler On
400	BR Sprinkler On

5.4.1 Observations

The observations are presented as a series of images captured from eight camera locations, six were video cameras and two were thermal imaging cameras. The camera positions are shown in Figure 4.1.3-1.

Figure 5.4.1-1 through Figure 5.4.1-12 present sets of eight images, one from each camera position, at a given time, from the time of ignition to 420 s after ignition. Each image view is labeled. The first four views at the top of each figure show the west wall and window of the structure and then follow a path through the interior of the structure with a view of the bed room, the living room and a view (looking west) through the open door to the corridor. The second set of four views, at the bottom of each figure, provides a video view of the north east portion of the corridor and a view of the inside of the target room door. The thermal imaging cameras provide a view of the east corridor, looking north, and a view of the inside of the target room.

Figure 5.4.1-1 shows the conditions at the time of ignition. At this point, the six video views are clear and unobstructed. The thermal images provide limited thermal contrast because the surfaces in the view are at similar temperatures.

The images in Figure 5.4.1-2 were captured 60 s after ignition. At this point the fire is still limited to the trash container fuel package. The fire development in this experiment was slower than in the previous experiments. There is a thin, light smoke layer formed in the bedroom. There was no smoke or change in thermal condition in the living room, target room or corridor at this time.

The images in Figure 5.4.1-3 were recorded at 120 s after ignition. The portions of the bed and the chair are involved in fire. The smoke layer in the bedroom has gotten darker in color was approximately 0.61 m (2.00 ft) thick throughout the bedroom and smoke had flow flowed into the hall. Little if any smoke had flowed into the living room or the corridor at this time.

Figure 5.4.1-4 shows the images recorded 60 s later at 180 s after ignition. The volume involved in fire has increased. The hot gas layer in the bedroom has become thicker, extending down 1.52 m (5 .00ft) from the ceiling. A hot gas layer has also formed in the living room. It is also approximately 1.52 m (5 .00ft) thick. Smoke and heat are shown flowing into the corridor. The target room appears clear of smoke and thermal view of target room does not show any noticeable heat infiltration.

The window vented due to flame impingement at 208 s after ignition. More than 75 % of the window opening was cleared naturally. Some shards of glass remained at the bottom that were removed manually. The images in Figure 5.4.1-5, were recorded at 218 s after ignition just after the window opening was fully vented. The flames can be seen flowing out of the top of the window opening against the wind. Soot obscured the video views in the living room and both of the cameras in the corridor. The image from the corridor IR camera shows hot gases exiting the living room, filling the doorway top to bottom and impinging on the east wall of the corridor. Small streams of smoke and heat were flowing around the a large portion of the of the door into the target room, as shown in both the video and thermal image of the target room.

Figure 5.4.1-6 shows the conditions at 234 s after ignition. Flames can be seen rolling out of the entire window opening. Horizontal flames are shown extending from the bedroom through the living room and out through the doorway into the corridor. In the corridor video view, the flames that pushed out of the living doorway can barely be seen through the thick smoke. The thermal camera view of the corridor gives the sense of horizontal (jet flame) nature of the hot gases extending across the corridor. In the target room, flames are shown coming under the bottom of the door. The thermal image from the target room exhibits heat around the door edges and a thermal plume from the bottom of the door.

The images in Figure 5.4.1-7 were recorded at 240 s after ignition. The image from the bedroom window was captured between pulses of flame coming out of the opening. Based on the video images, the conditions throughout the rest of the test structure are very similar to those described in the previous figure. The thermal image from the corridor shows that the heat had moved down closer to the floor.

The images in Figure 5.4.1-8 were taken just prior to the deployment of the small wind control device. The bedroom was still in a post-flashover fire condition with some flames extending out of the window opening. The thermal view of the corridor was obscured from the heat. The thermal image was deteriorated due to the high thermal exposure. The target room video view continued to show the flames at the bottom of the target room door. The thermal view from the target room shows the outlines of the thin sections of the door, as the door had increased in temperature.

The WCD was deployed at 271 s after ignition. Figure 5.4.1-9 has images that were recorded at 275 s after ignition. The wind control device was in place over the window opening as shown in the outside view. The interior video views were obscured. The thermal view of the corridor was still obscured due to high heat conditions. Flames had come through most of the door perimeter as shown in the video image from the target room, although the fire at the base of the door had gotten smaller. The thermal image from the target room, compliments that video image, in that most of the thermal plume from the bottom of the door was no longer visible.

Figure 5.4.1-10 shows the conditions at 300 s after ignition, or approximately 30 s since deployment of the wind control device. The interior video views were still obscured by soot. The thermal image from the corridor was still saturated with heat. In the target room the flames were still burning along portions of the edges and the bottom of the door. The thermal image of the target room door had not changed significantly since the previous image.

Figure 5.4.1-11 shows the conditions at 360 s after ignition. At this point the water spray sprinkler in the window opening had been flowing for almost 30 s. The only noticeable changes between this set of images and Figure 5.4.1-10, occurred in the target room images. The flames are no longer visible in the video view and the thermal view of the door shows that more heat had transferred through and around the door.

Figure 5.4.1-12 contains images recorded at 420 s after ignition. The safety sprinkler in the bedroom had been manually activated at 400 s after ignition. No significant differences are shown between these images and the images in the previous figure.

Figure 5.4.1-1. Experiment 4, ignition.

Figure 5.4.1-2. Experiment 4, 60 s after ignition.

Figure 5.4.1-3. Experiment 4, 120 s after ignition.

Figure 5.4.1-4. Experiment 4, 180 s after ignition.

Figure 5.4.1-5. Experiment 4, window fully vented, 218 s after ignition.

Figure 5.4.1-6. Experiment 4, corridor flames, 234 s after ignition.

Figure 5.4.1-7. Experiment 4, 240 s after ignition.

Figure 5.4.1-8. Experiment 4, 268 s after ignition, just prior to WCD deployment.

Figure 5.4.1-9. Experiment 4, WCD in place, 275 s after ignition.

Figure 5.4.1-10. Experiment 4, 300 s after ignition.

Figure 5.4.1-11. Experiment 4, 360 s after ignition.

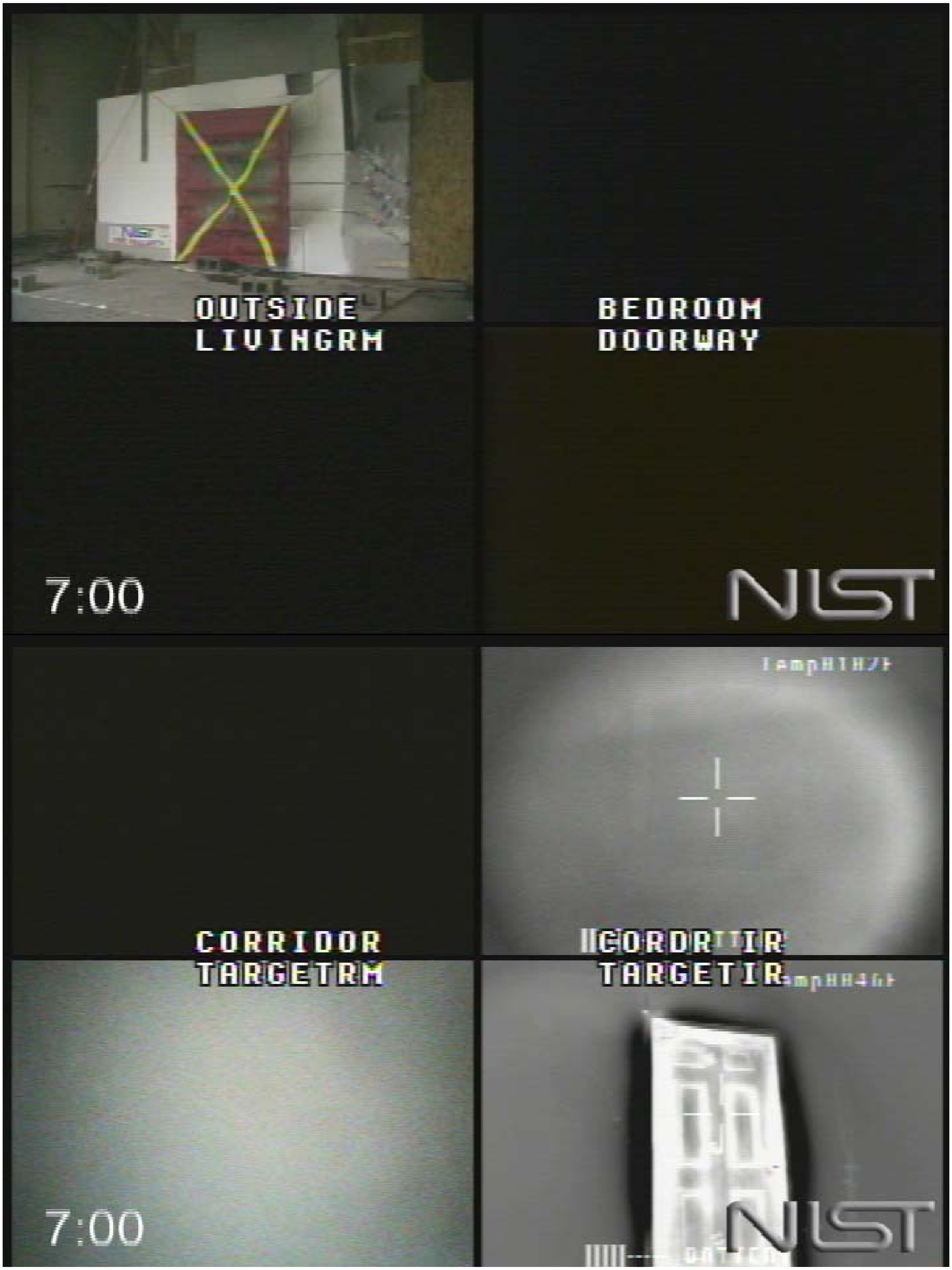

Figure 5.4.1-12. Experiment 4, 420 s after ignition.

5.4.2 Heat Release Rate

The heat release time history is shown in Figure 5.4.2-1. As noted in the observations, this fire developed slower than the previous experiments, as a result the combustion products that had left the structure and flowed into the calorimeter only generated approximately 200 kW at the time of window failure. Within 60 s after the window was vented, the heat release rate peaked at approximately 27 MW. Due to ventilation constraints, the heat release rate began to decrease and was just below 20 MW when the small WCD was deployed. At the time that the window sprinkler was turned on, 332 s after ignition, the heat release rate had been reduced to 1.5 MW.

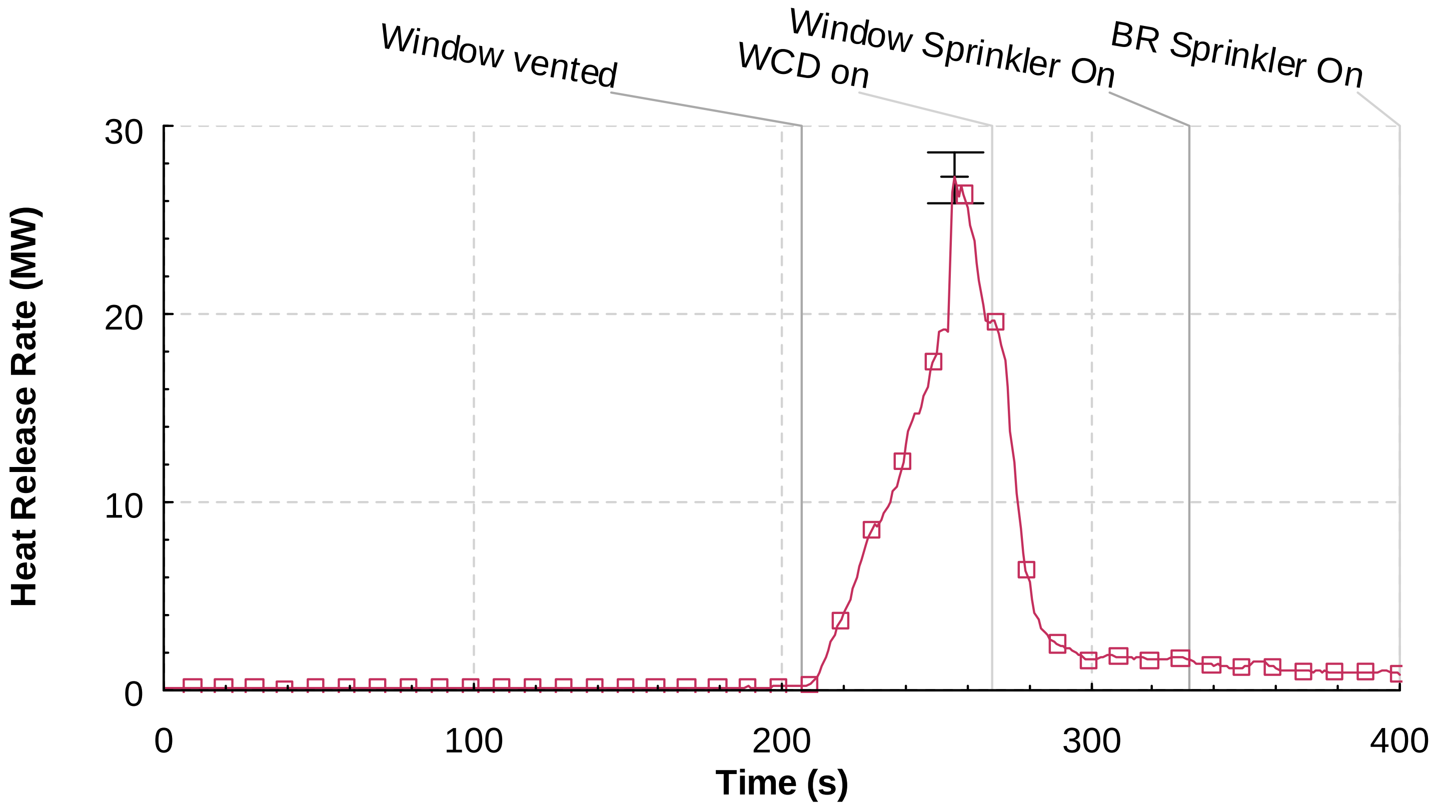

Figure 5.4.2-1. Heat release rate versus time, Experiment 4.

5.4.3 Temperatures

Figure 5.4.3-1 through Figure 5.4.3-11 provide the temperature measurements from the thermocouple arrays shown in Figure 4.1.3-1. The figures are given in order from the western most measurement point, the bed room window opening, and moving through the structure toward the east; bedroom, hall, living room, corridor, south and southwest portions of the corridor (closed end) and then to the north section of the corridor and ending with the exhaust vent. The last temperature graph provides temperatures from the thermocouple array centered in the target room.

The three thermocouples located in the window opening, shown in Figure 4.1.3-1, provide insight into the ventilation conditions at the window. Prior to failure of the window at 208 s after ignition, there is no significant increase in temperature outside of the window. Once the window was vented, the temperatures increased. Recalling the observations of the flame pulsing in and out of the window, accounts for the oscillatory nature of the temperature data. However the temperature range seems low when compared with videos.

After the WCD is deployed, the thermocouples are under the WCD, shielded from the wind and the temperatures increased by approximately a factor of five. The temperature began to decline prior to the window sprinkler activation. Once the window sprinkler was turned on the temperature With the WCD in place localized burning occurred in the bedroom which may have resulted in the temperature spikes at approximately 240 s after ignition. The temperatures were in decline prior to the removal of the WCD and continued to decrease after the WCD was removed.

The measurements from the thermocouple array located in the center of the bedroom are given in Figure 5.4.3-2. Prior to the window failure, the temperatures in the bedroom increased from ambient conditions to a peak of approximately 700 ºC (1292 ºF) near the ceiling. At the same time, the temperatures, 2.13 m (7.00 ft) below the ceiling, were almost 100 ºC (212 ºF). After the window vented, there was a slight decrease in temperatures near the ceiling, however within seconds, all of the temperatures increased. Within 20 s of the window failure, the bedroom had transitioned to post-flashover conditions. All of the temperatures in the bedroom were in excess of 800 ºC (1472 ºF) at this time. The WCD was deployed at 271 s. Within 60 s of the WCD deployment, temperatures had decreased from in excess of 800 ºC (1472 ºF) to less than 500 ºC (932 ºF). The window sprinkler was activated at 332 s after ignition. The impact of the water spray was a reduction in temperatures in excess of 400 ºC (752 ºF) to approximately 200 ºC (392 ºF).

The data from the hall thermocouple array is presented in Figure 5.4.3-3. Prior to the window failure, the temperatures near the ceiling increased to approximately 400 ºC (752 ºF) and a hot gas layer formed that extended from the ceiling down to at least 1.52 m (5.00 ft) below the ceiling. After the window vented, all of the temperatures more than doubled in less than 30 s. Just prior to the deployment of the WCD, the temperatures in the hall, ceiling to floor, averaged approximately 800 ºC (1472 ºF). The impact of the WCD can be seen as the aggregate temperatures decreased from approximately 800 ºC (1472 ºF) to less than 400 ºC (752 ºF) in less than 60 s. The impact of the window sprinkler can be seen as the temperatures were reduced to half their value within 20 s. After the initial sprinkler induced decrease, the range of temperatures increased with peak temperatures of approximately 200 ºC (392 ºF). At the end of the experiment, the thermocouple values did not stratify in order of place relative to the distance below the ceiling. This may have been caused by water deposition on some of the individual thermocouples.

The living room had two thermocouple arrays, a corner array and an array in the center of the living room which was in the direct flow path between the hall and the corridor. The temperatures from the corner array are provided in Figure 5.4.3-4. The peak temperature prior to window failure was approximately 180 ºC (356 ºF) at the locations near the ceiling. After the window vented, all of the temperatures at this position increased to more than 700 ºC (1292 ºF). The temperatures leveled off prior to the deployment of the WCD. Within 60 s of deployment of the WCD, the temperatures decreased from more than 650 ºC (1202 ºF) to less than 350 ºC (662 ºF). The temperatures continued to decrease after the window sprinkler was activated. In less than 60 s, the aggarate average temperature was approximately 200 ºC (392 ºF).

The temperature measurements from the center of the living room are shown in Figure 5.4.3-5. The again the temperature responses to the fire and WCD events are similar to those in the hall. Being in the flow path between the hall and the corridor, the living room temperature values are a closer match to the hall values and in terms of magnitude and oscillatory nature, as opposed to the steady and slightly cooler temperatures exhibited in the corner of the living room. Being in the flow path, the center of the living position is more susceptible to convective heating and cooling as evidenced by the large temperature swings. After the WCD was deployed, the temperatures at this position became similar and began to decrease. Within 60 s after WCD deployment the temperature in the living had decreased by more than 50 %. The window sprinkler continued reduce the tempeatures by more than 100ºC (212 ºF) during the first 60 s of application time.

Figure 5.4.3-6 gives the corridor center position thermocouple array measurements, which is located just east of the doorway from the living room to the corridor. Temperatures indicative of a hot gas layer, extending from the ceiling down to 1.22 m (4.00 ft) below the ceiling, existed just prior to the window being vented. After the window vented, the temperatures from the ceiling to the floor increased to more than 700 ºC (1292 ºF) within 20 s. After WCD deployment, temperatures at this position decreased to approximately 200 ºC (392 ºF) within 60 s. The water from the window sprinkler only had a small impact on the temperature at this position. After window sprinkler activation the temperatures decreased an additional 50 º C (122 ºF).

The temperature measurements from the thermocouple arrays in the south and southwest areas of the corridor are given in Figure 5.4.3-7 and Figure 5.4.3-8Figure 5.2.3-8. The south corridor position exhibited a temperature increase on the order of 600ºC (1112 ºF) within 30 s after the window was vented. The temperatures were in the range of 500ºC (932 ºF) to 600ºC (1112 ºF) just prior to the WCD deployment. After the WCD was put in place, the temperatures at the south corridor position stratified. The temperature at 0.30 m (1.00 ft below the ceiling) reduced from approximately 550 ºC (1022 ºF) to 350 ºC (662 ºF) within 60 s of the wind being blocked. During the same period, the temperature 2.13 m (7.00 ft) below the ceiling reduced from approximately 550 ºC (1022 ºF) to 150 ºC (302 ºF). The impact of the water spray from the window sprinkler had limited impact at this position. After window sprinkler activation, the temperature near the ceiling was reduced approximately 100 ºC (212 ºF), while the measurement closest to the floor only decreased by approximately 50 º C (122 ºF).

Figure 5.4.3-8 shows the temperatures at the southwest corridor position. This position was the most remote from the direct flow path between the bedroom window opening and the ceiling vent in the northwest corridor. As a result the temperatures are generally lower and after the wind driven flow was interrupted by the WCD device the temperatures tended to stratify. In this experiment the peak temperatures after window failure were less than half of the peak temperatures at any location in the direct flow path and the corridor south position. After the deployment of the WCD, the temperatures decreased by approximately 100 º C (212 ºF) after 60 s. After activation of the window sprinkler the temperatures continued to decrease by approximately 50 º C (122 ºF). Note that one of the thermocouple channels did not function properly in this experiment. The thermocouple at 0.91 m (3.00 ft) below the ceiling was shorted at a location that remained at ambient temperature.

The temperature measurements from the corridor north position are displayed in Figure 5.4.3-9. The peak temperature at that position, prior to the venting of the window, was less than 200 ºC (392 ºF). Within 30 s after the window failed, the temperatures at this position increased to an aggregate average of approximately 750 ºC (1382 ºF). The deployment of the WCD resulted in a significant decrease of the temperatures, such that the peak temperatures were approximately 250 ºC (482 ºF) or less. Activation of the window sprinkler resulted in an additional decrease by approximately 50 ºC (122 ºF) at this position.

The temperatures at the exhaust vent are given in Figure 5.4.3-10. All of the temperatures are consistent with the trend of the temperatures from the north corridor position.

The measurements from the thermocouple array in the center of the target room are given in Figure 5.4.3-11. No increase in temperature was evident until after the window was vented. The temperatures in the room did not decrease due to the deployment of the WCD until approximately 30 s after the action. The temperature 0.03 m below the ceiling continued to increase after the WCD was deployed due to localized burning around the door. It is not clear how much of the continued cooling in the target room was a function of the window sprinkler, given that the steel door remained intact throughout the experiment.

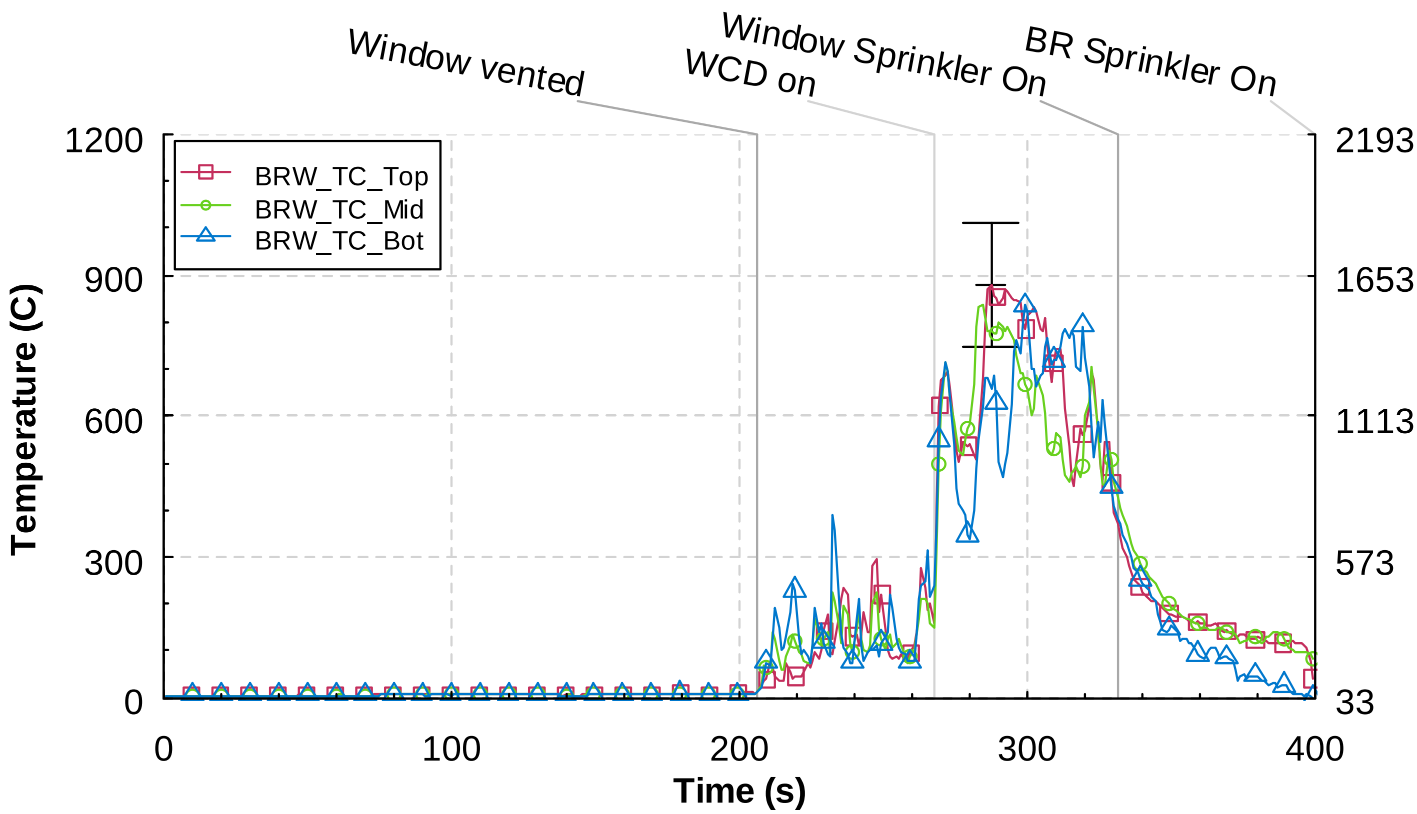

Figure 5.4.3-1. Temperature versus time from the bedroom window (BRW) thermocouple array, Experiment 4.

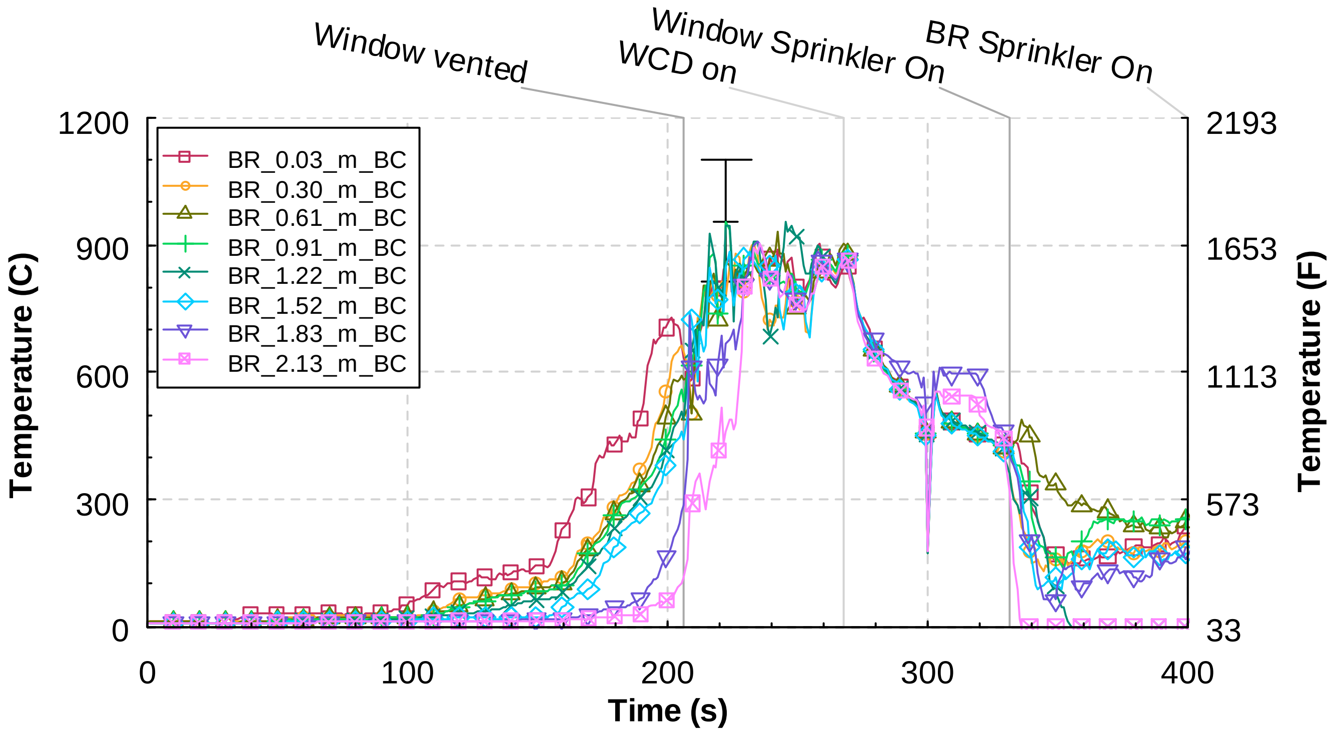

Figure 5.4.3-2. Temperature versus time from the bedroom (BR) thermocouple array, Experiment 4.

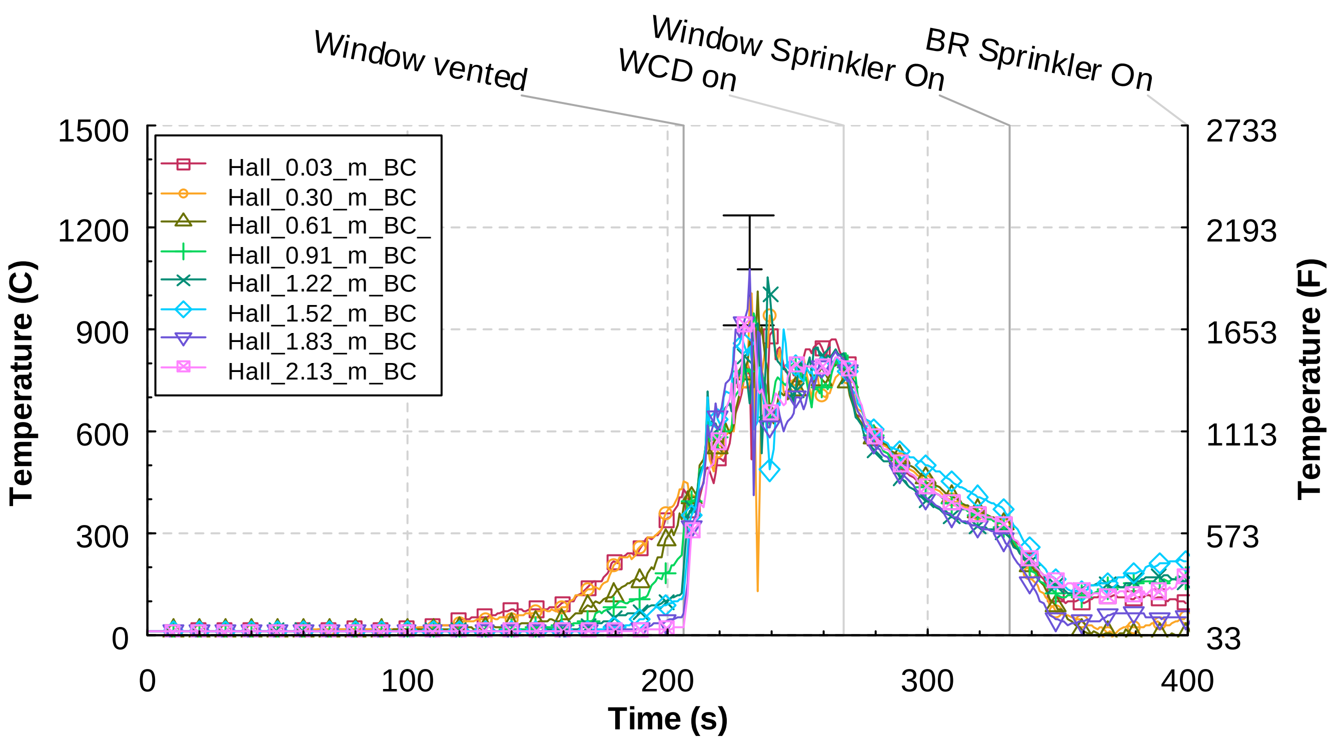

Figure 5.4.3-3. Temperature versus time from the hall thermocouple array, Experiment 4.

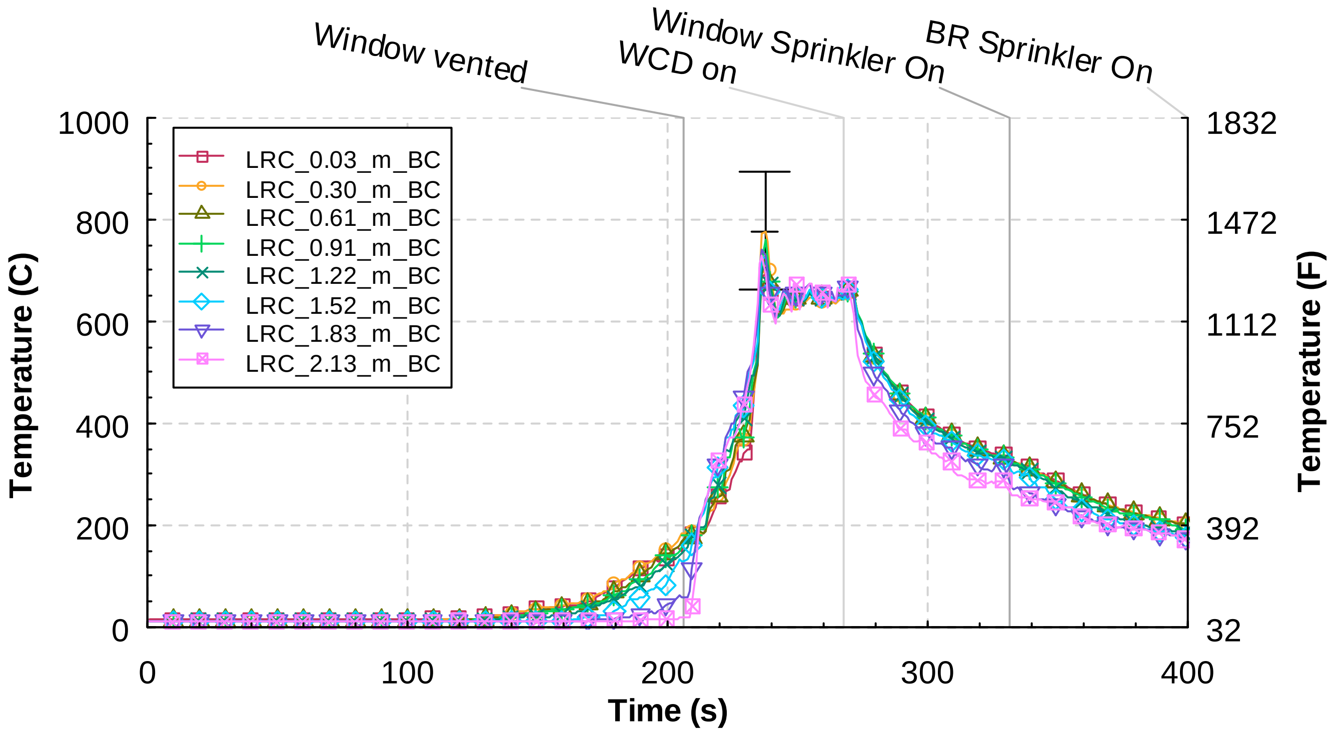

Figure 5.4.3-4. Temperature versus time from the living room corner (LRC) thermocouple array, Experiment 4.

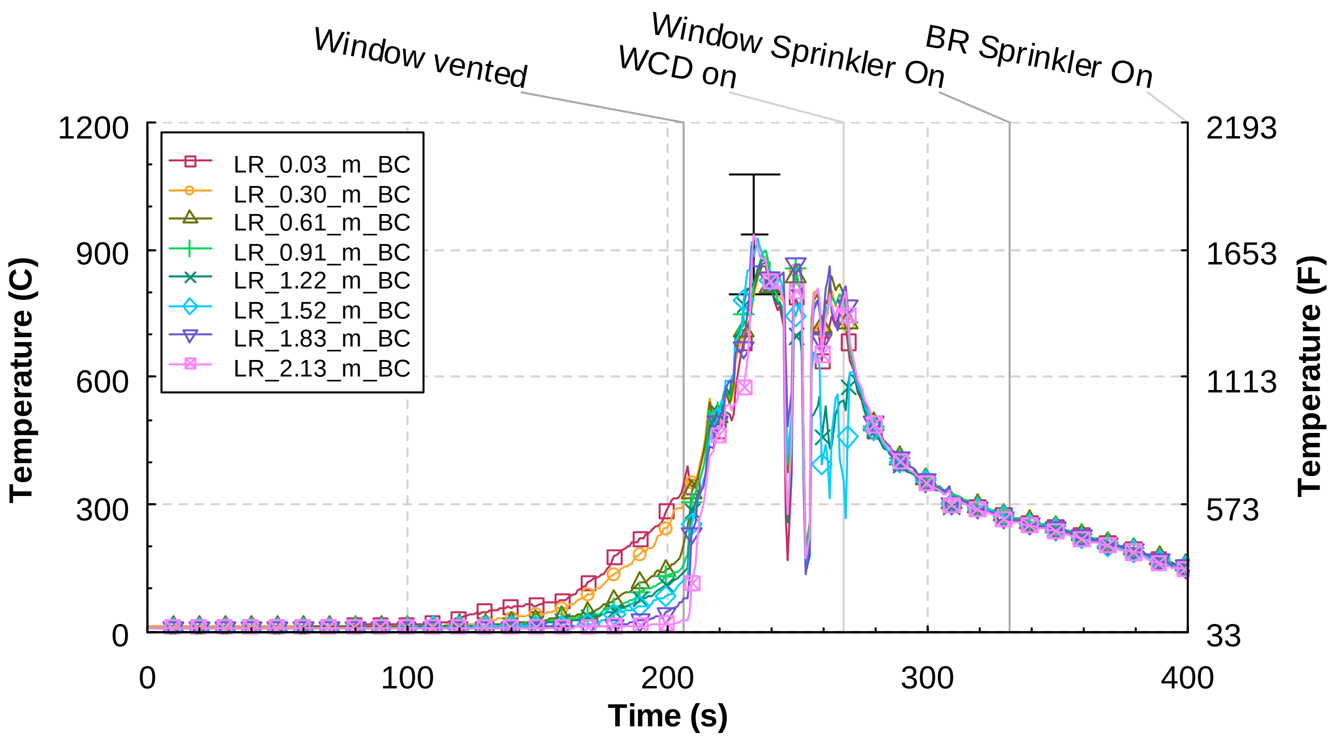

Figure 5.4.3-5. Temperature versus time from the living room (LR) thermocouple array, Experiment 4.

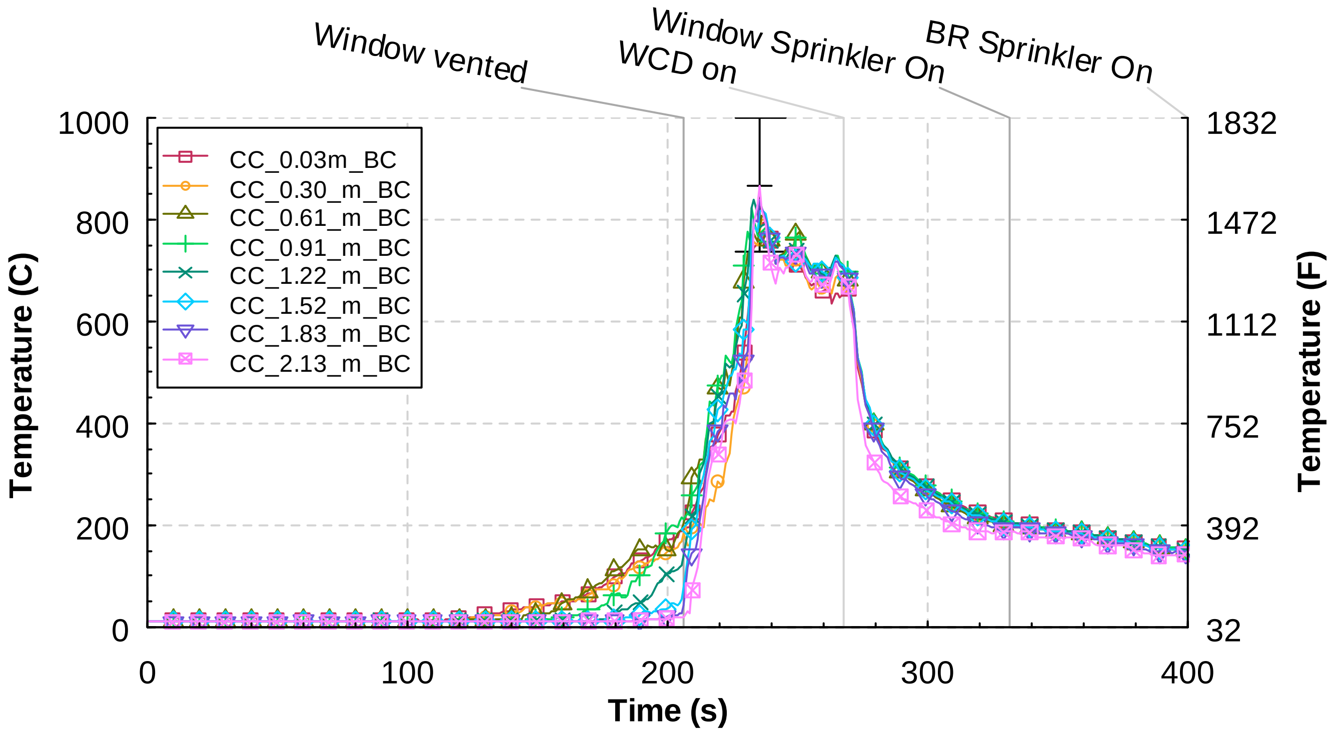

Figure 5.4.3-6. Temperature versus time from the corridor center (CC) thermocouple array, Experiment 4.

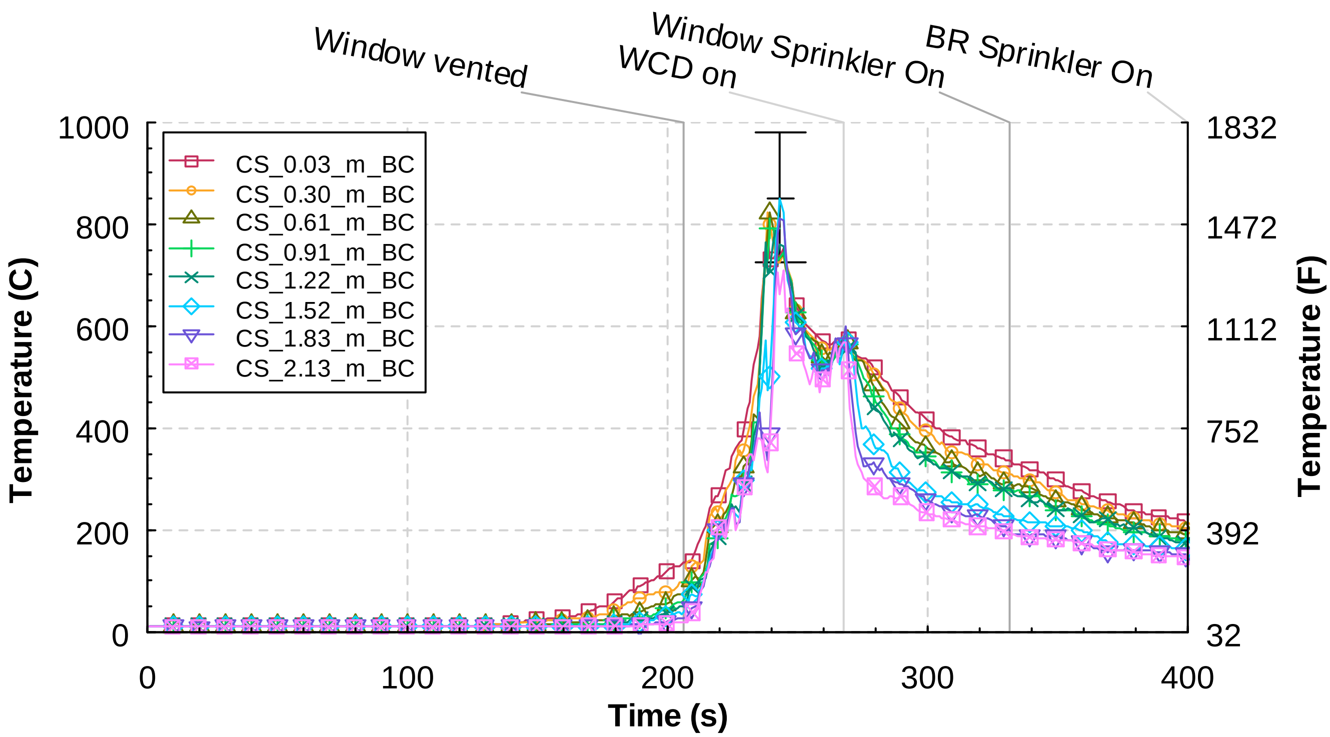

Figure 5.4.3-7. Temperature versus time from the corridor south (CS) thermocouple array, Experiment 4.

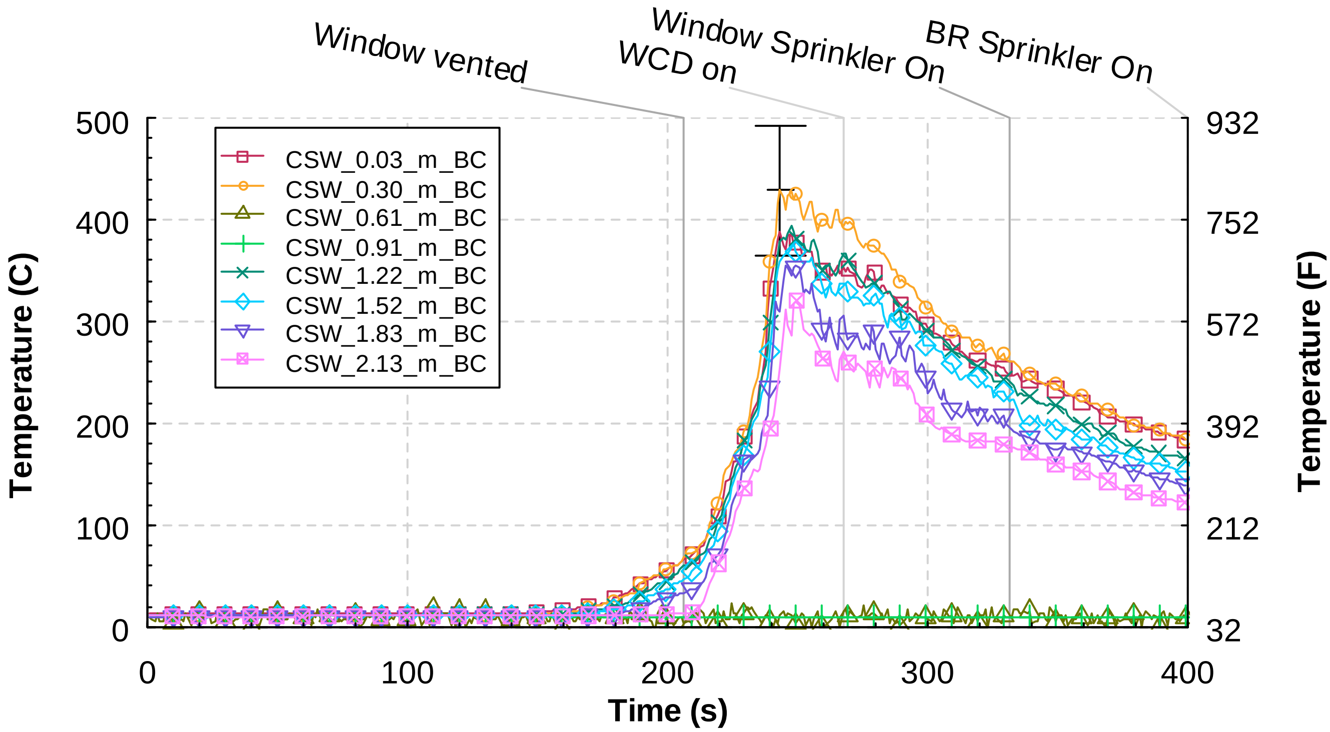

Figure 5.4.3-8. Temperature versus time from the corridor southwest (CSW) thermocouple array, Experiment 4.

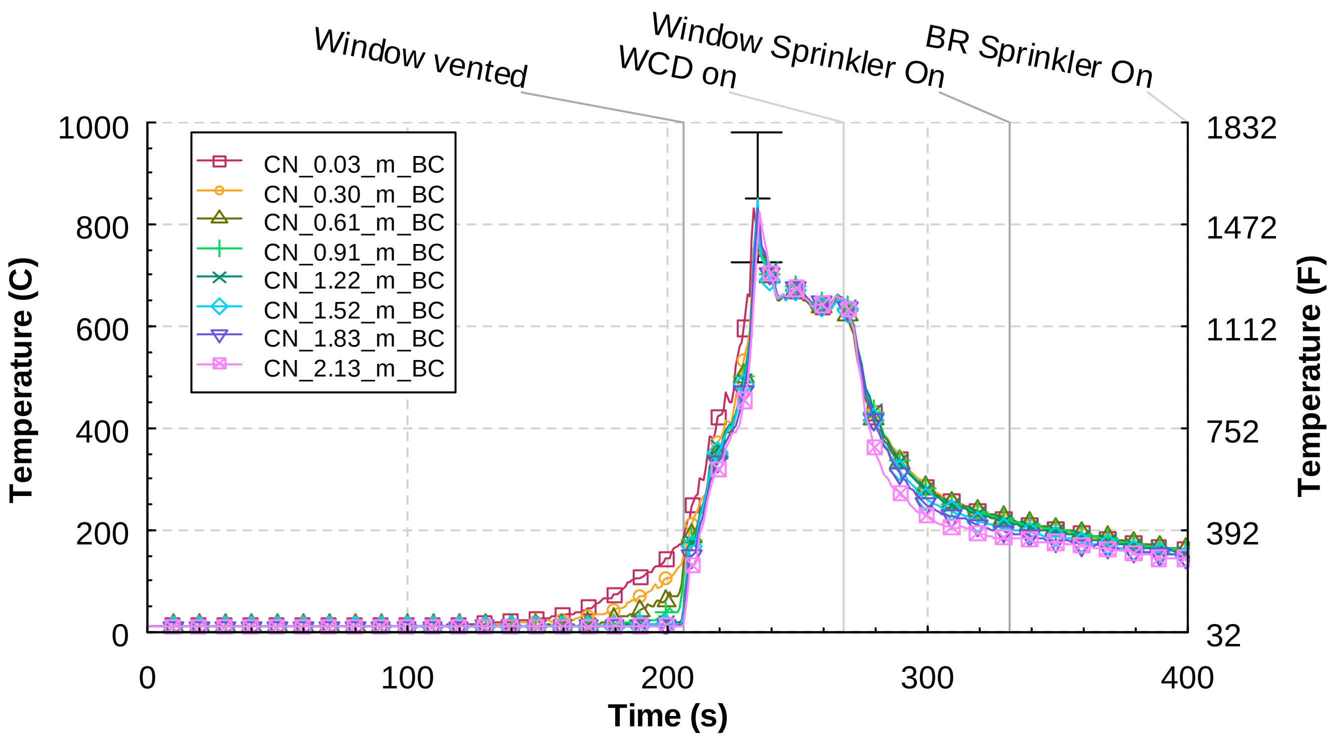

Figure 5.4.3-9. Temperature versus time from the corridor north (CN) thermocouple array, Experiment 4.

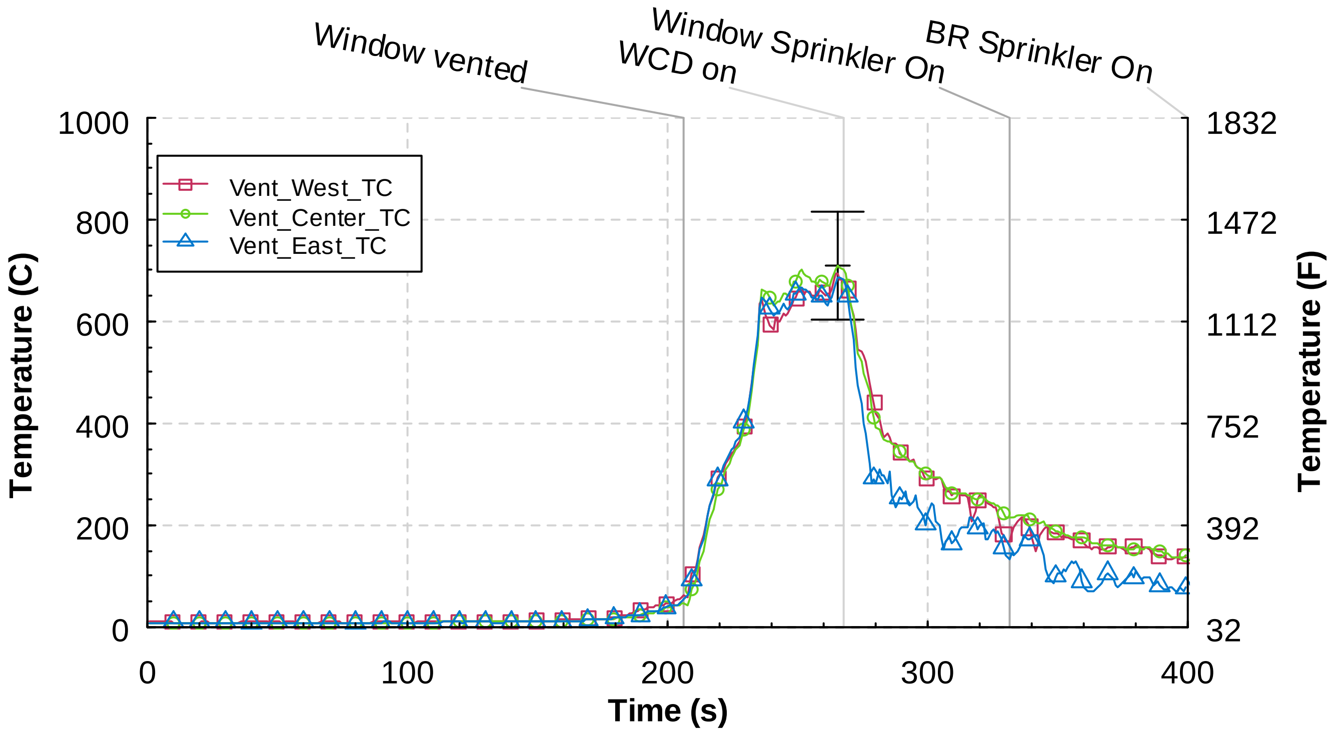

Figure 5.4.3-10. Temperature versus time from the ceiling vent thermocouple array, Experiment 4.

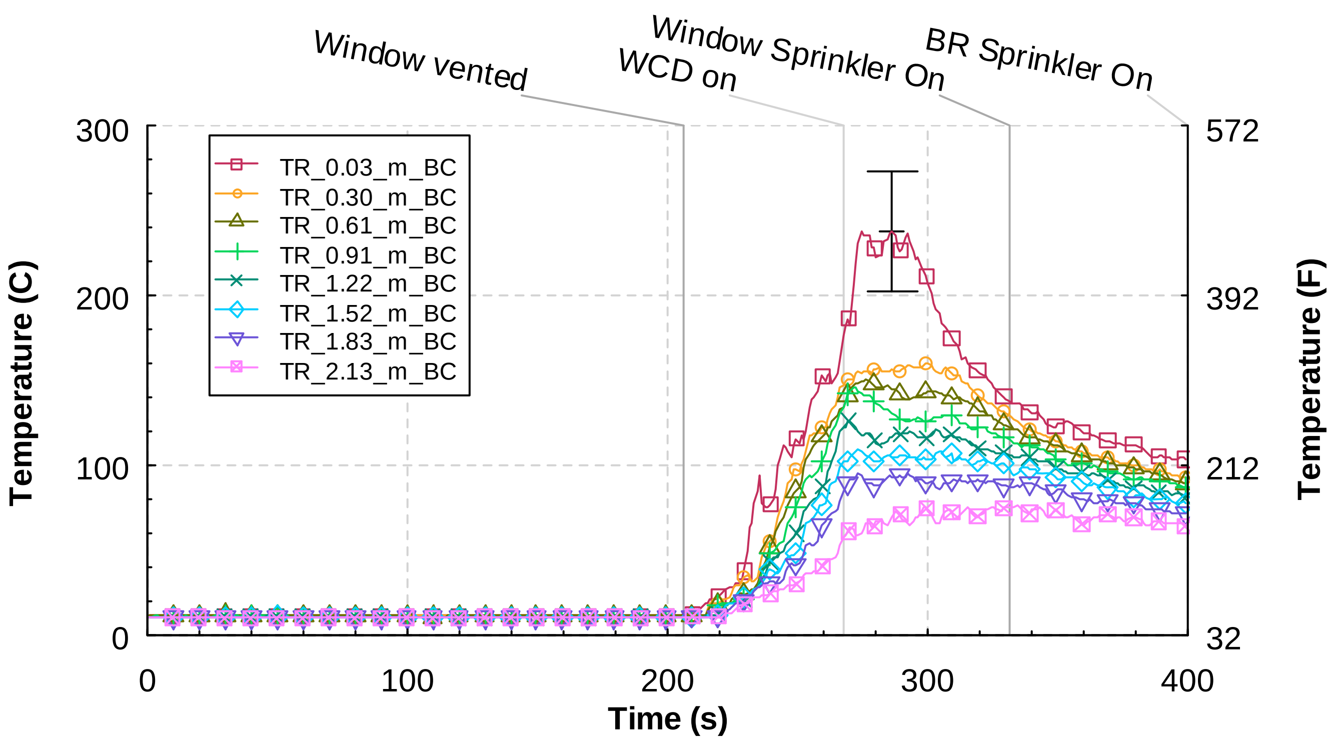

Figure 5.4.3-11. Temperature versus time from the target room (TR) thermocouple array, Experiment 4.

5.4.4 Heat Flux

Figure 5.4.4-1 shows the measurements from the heat flux gauges located in the bedroom, living room and three locations in the corridor. The heat flux in the bedroom exceeded 30 kW/m^2 just prior to the venting of the window. Just after the window vented, the heat flux in the bedroom decreased but the heat fluxes at the hall and corridor locations increased as the wind moved the hot gases through the structure. Peak heat fluxes, just prior to the deployment of the WCD, ranged from approximately 150 kW/m^2 in the bedroom to 70 kW/m^2 in the southwest corridor. Within 60 s of the WCD deployment, the heat fluxes in the corridor were reduced to approximately 10 kW/m^2 . The heat flux in the bedroom decreased to approximately 35 kW/m^2 and then began to increase. It reached approximately 50 kW/m^2 at the time of window sprinkler activation. The water spray reduced the heat flux in the bedroom to 20 kW/m^2 within 60 s of activation. The heat fluxes in the corridor were reduced slightly, resulting in heat fluxes of 10 kW/m^2 or less.

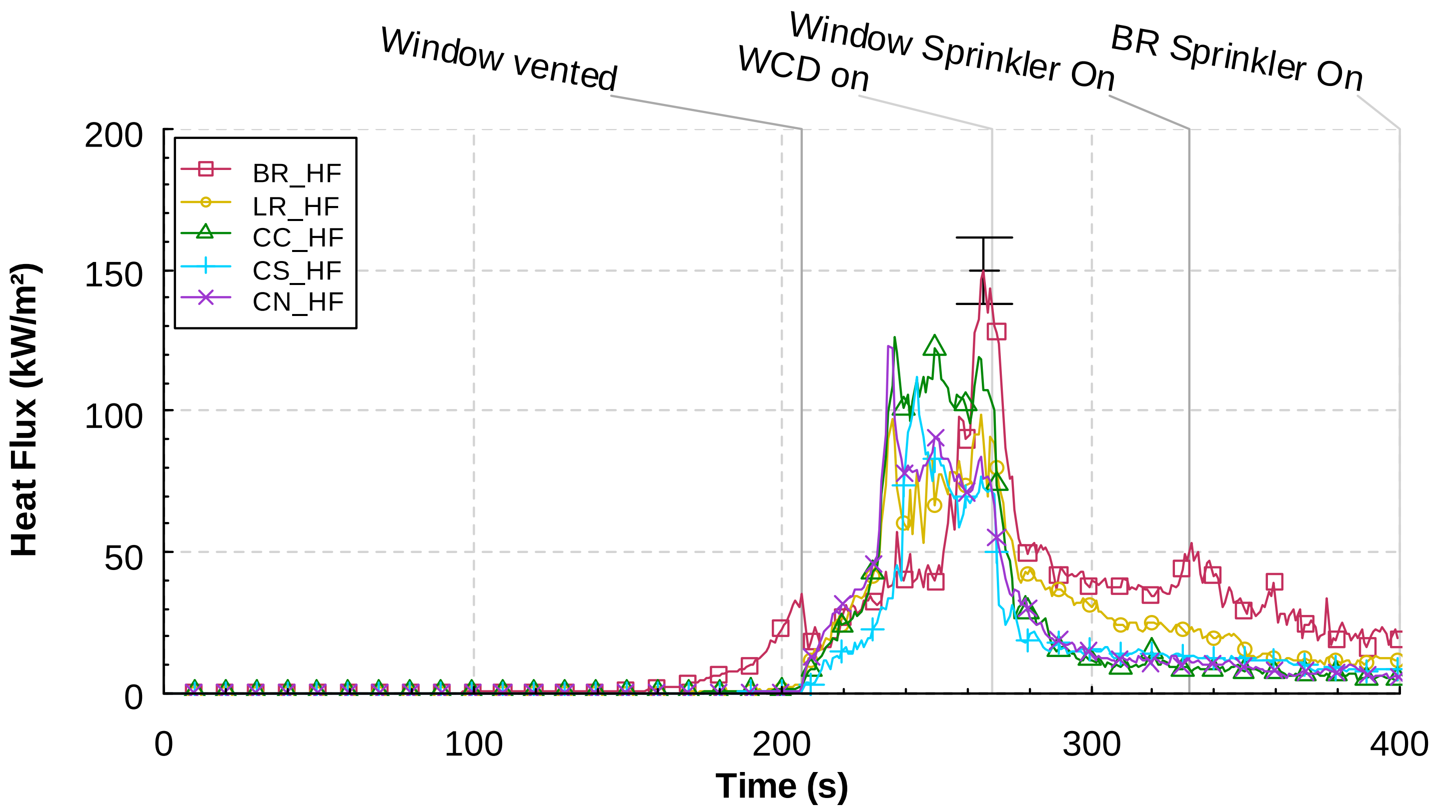

Figure 5.4.4-1. Heat flux versus time at five locations, Experiment 4.

5.4.5 Pressure

Figure 5.4.5-1 shows the measurements from the pressure sensors located in the bedroom, living room and three locations in the corridor. The pressures throughout the structure increased as the fire developed. The highest pressure was recorded in the bedroom and the lowest pressure in the northwest corridor position below the ceiling vent. Within seconds after the WCD was deployed, the pressures went uniformly negative. The window sprinkler had no significant affect on the pressures.

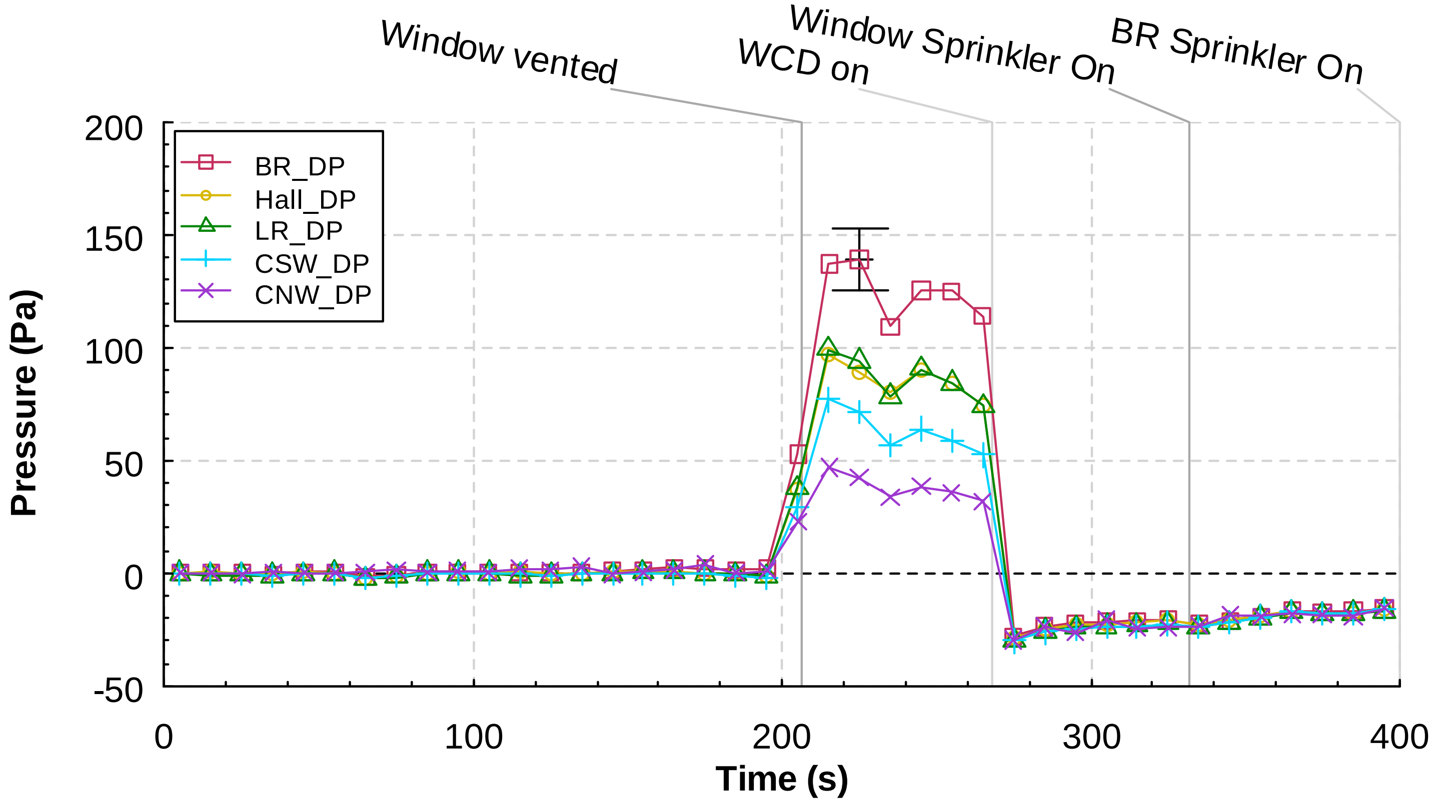

Figure 5.4.5-1. Pressure versus time at five locations, Experiment 4.

5.4.6 Velocities

Figure 5.4.6-1 through Figure 5.4.6-5 show the velocity measurements from the arrays of bi-directional probes located as shown in Figure 4.1.3-1. The velocity graphs are in order from west to east starting with the window position and ending with the bi-directional probes in the vertical vent in the northwest portion of the corridor.

Figure 5.4.6-1 provides the velocity measurements from the bi-directional probes that are located outside of the structure, 60 mm to the west of the window. These bi-directional probes are positioned at 0.38 m (1.25 ft), 0.76 m (2.50 ft) and 1.14 m (3.75 ft) below the top of the window opening, centered on north south axis, as shown in Figure 4.1.3-3. The back face of the probe was 60 mm (0.20 ft) in front of the window glass, as a result there is no measured velocity until after the window began to vent. The window was vented at 208 s after ignition. Positive velocities are flowing into the window.
The flames and combustion products venting out of the upper portion of the window account for the reduction of the velocity at the upper and middle window positions to approximately 1 m/s (2 mph).

Figure 5.4.6-2 shows the velocities at the hall array position. On this graph, the positive direction is from west to east. As noted in previous experiments, the bi-directional probe located 0.30 m (1.00ft) below the ceiling is in the wake area of the doorway lintel, hence it has a lower velocity than the other two probes at this location. The lower probes exhibit velocities of approximately 11 m/s (25 mph) just prior to the WCD deployment. Within 60 s of the WCD being put in place, the velocities were reduced to approximately 1.5 m/s (3.4 mph) or less. The velocities continued to decrease after the window sprinkler was activated.

Figure 5.4.6-3 displays the velocities from the south corridor position. The positive direction is from north to south. While the window was still intact, the velocity of the ceiling jet/hot gas layer reached a peak velocity of less than 0.5 m/s (1.1 mph). After the window was vented the measurement indictated a highly mixed flow with no distinctive flow direction. Once the WCD was deployed the velocities are low, less than 1.5 m/s (3.4 mph), and had become uni-directional to the south.

The velocities from the north corridor position are shown in Figure 5.4.6-4. The positive flow direction for this location is from south to north. Prior to window failure, the ceiling jet/hot gas layer velocities reached a peak of approximately 1.0 m/s (2.2 mph) at 0.3 m (1 ft) below the ceiling. After the window vented the velocities increased to a peak of approximately 6.5 m/s (14.8 mph) at the probe located 2.13 m (7.00 ft) below the ceiling. Within 60 s after the WCD was deployed, the velocities at this location reduced to less than 1.0 m/s (2.2 mph). The window sprinkler had limited impact on the velocities at this location.

The measurements from the bi-directional probes installed in the exhaust vent, 2.44 m (8.0 ft) above the ceiling are given in Figure 5.4.6-5. The probes were spaced 0.51 m (1.67 ft) apart along the east-west centerline of the vent. The flow direction up and out of the structure is positive in the figure. After the window was vented, the velocities at all three probes were similar and in the same direction, flowing out of the structure. The average peak velocity of the three probes was approximately 9.5 m/s (21.6 mph). Application of the wind control device reduced the velocities to approximately 1.0 m/s (2.2 mph), just prior to the activation of the window sprinkler. Application of the sprinkler reduced the flow through the vent such that only the east and center probes were in the flow.

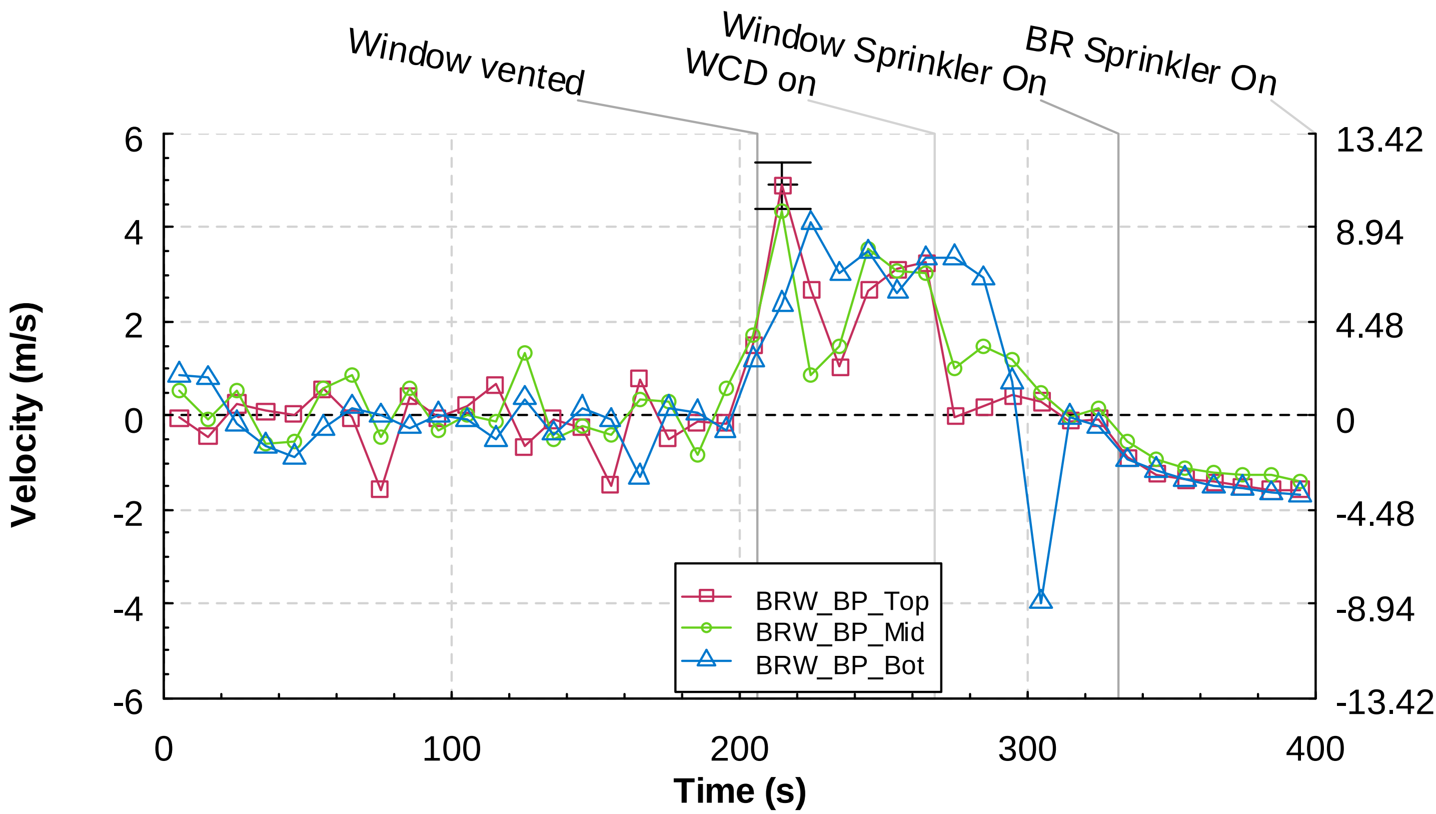

Figure 5.4.6-1. Velocity versus time from the bedroom window (BRW) bi-directional probe array, Experiment 4.

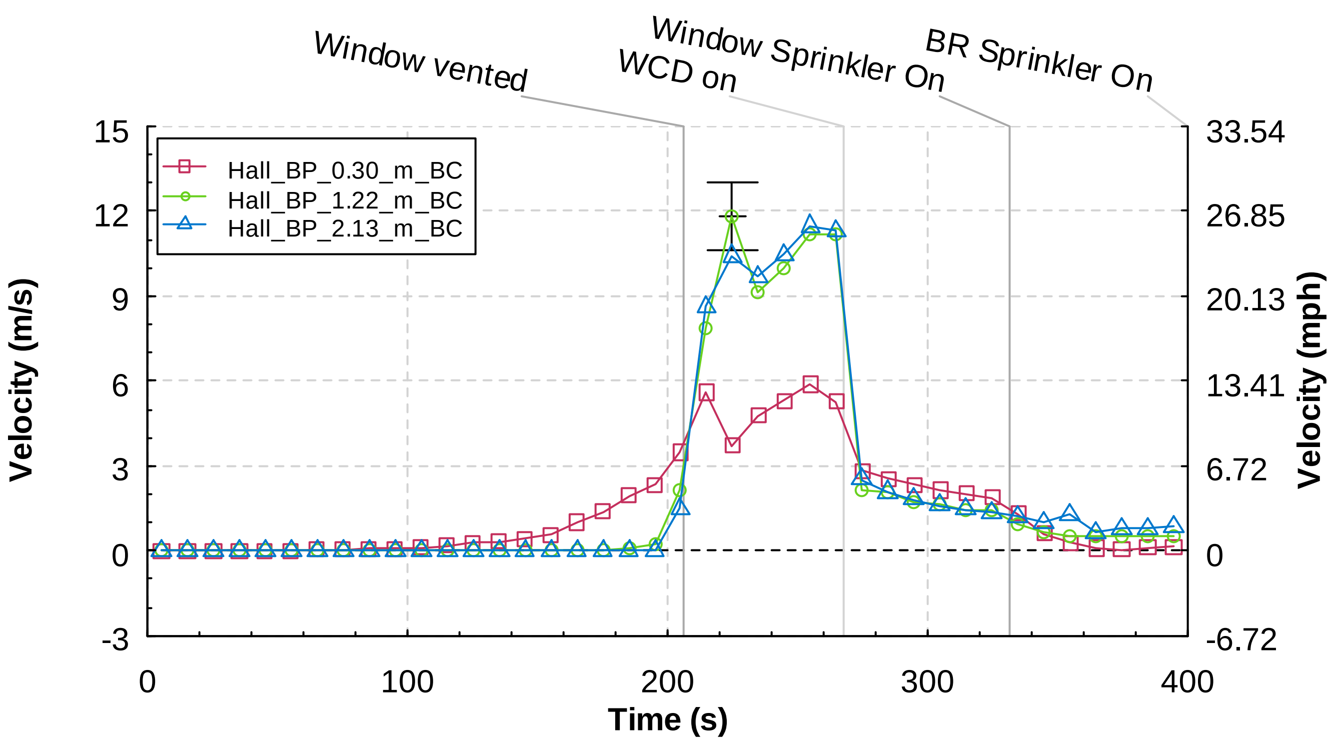

Figure 5.4.6-2. Velocity versus time from the hall bi-directional probe array, Experiment 4.

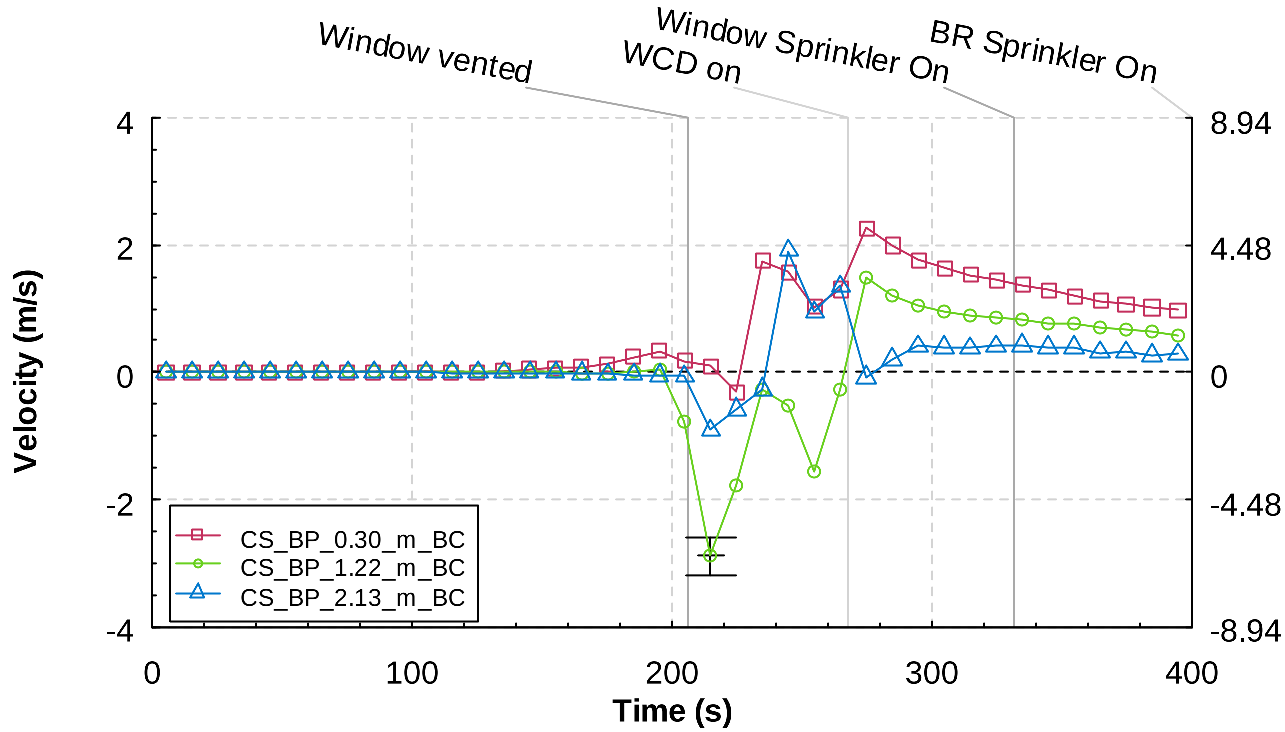

Figure 5.4.6-3. Velocity versus time from the corridor south (CS) bi-directional probe array, Experiment 4.

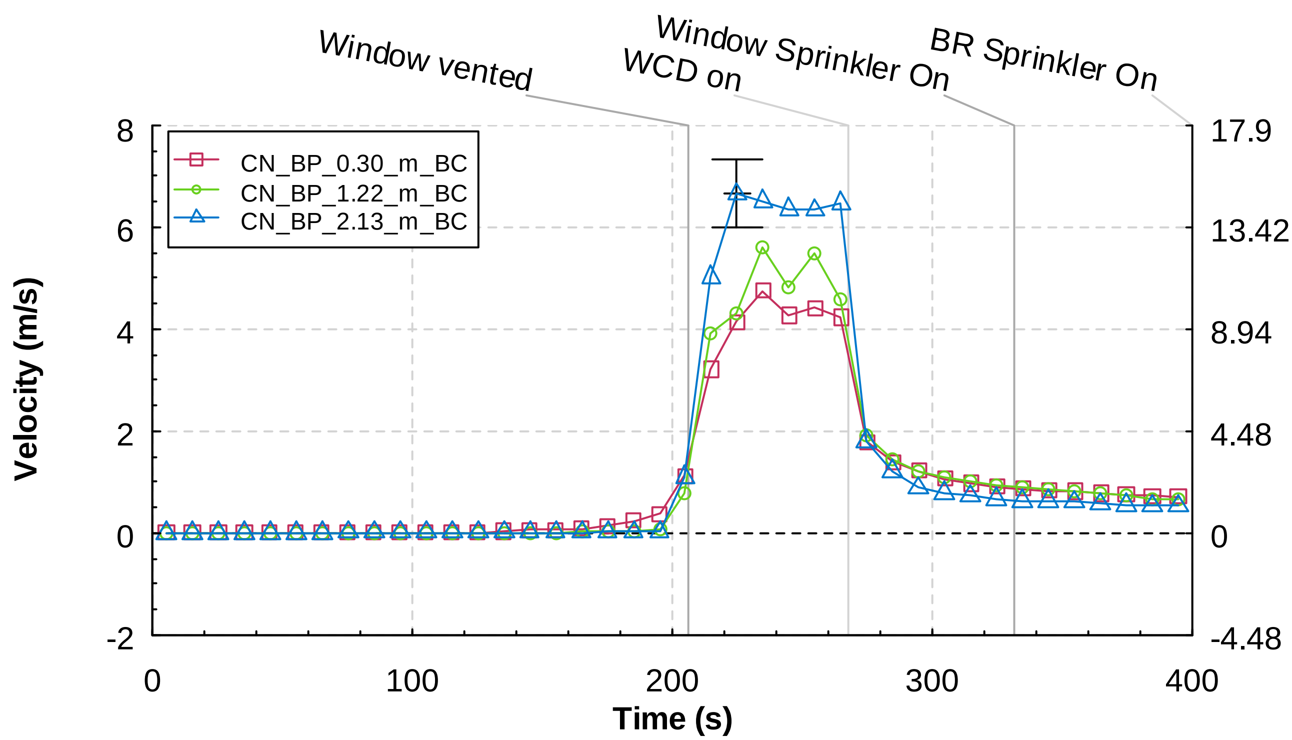

Figure 5.4.6-4. Velocity versus time from the corridor north (CN) bi-directional probe array, Experiment 4.

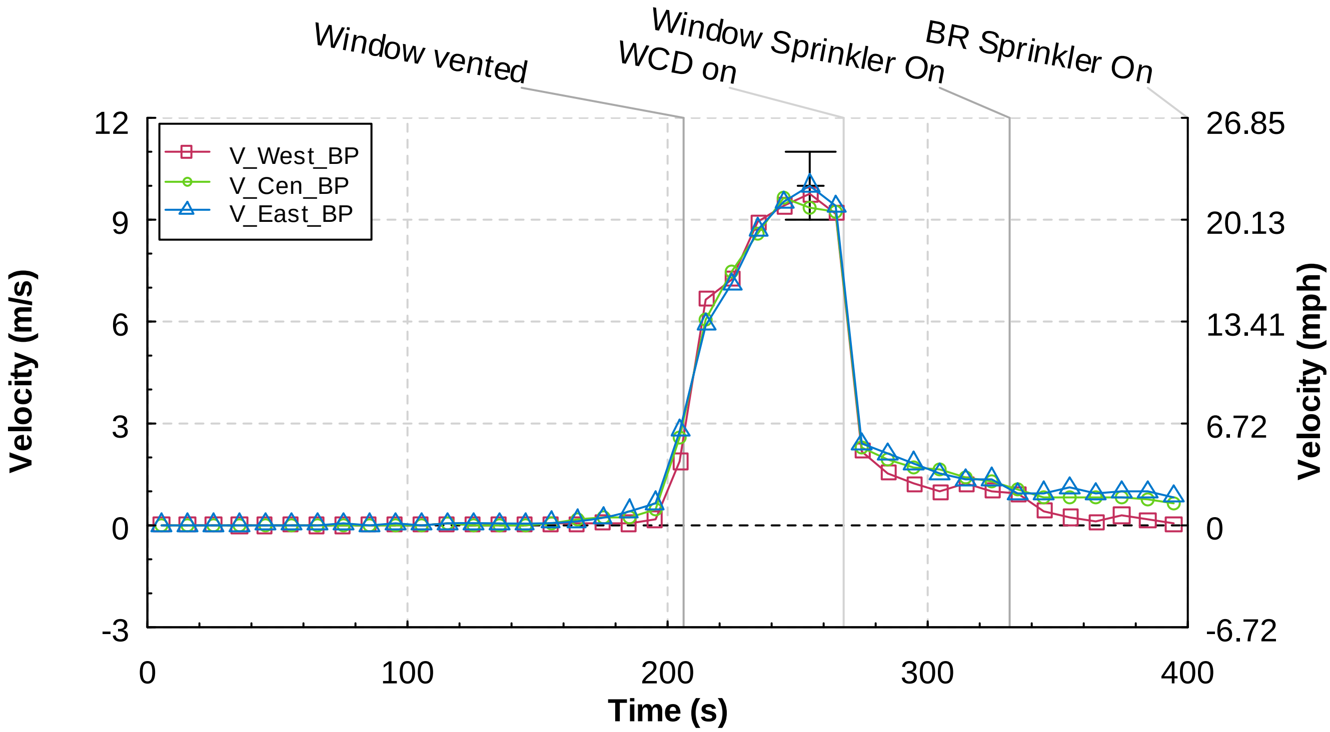

Figure 5.4.6-5. Velocity versus time from the ceiling vent (V) bi-directional probe array, Experiment 4.

5.4.7 Gas Concentrations

The gas concentration measurements for the bedroom and living room are given in Figure 5.4.7-1 through Figure 5.4.7-3. In this experiment, the upper probe was not available. The measurements from the lower bedroom probe are shown in Figure 5.4.7-1. As the fire in the bedroom developed, the oxygen concentration decreased and the carbon dioxide increased. After the window failed, the oxygen concentration increased for 25 s, then decreased to approximately 12 % at the time the WCD was deployed. Once the WCD was in place over the window opening, the oxygen decreased rapidly. During the same period, the carbon dioxide and carbon monoxide increased significantly. The measurements stopped short of the end of the experiment due to a malfunction in the sampling line.

Figure 5.4.7-2 and Figure 5.4.7-3 provide the measurements from the upper and lower gas sampling positions in the living room. The oxygen had decreased to approximately 19.5 % at the time of window failure. Immediately after window failure the, rate of oxygen depletion increased. At 250 s after ignition, the rate of oxygen depletion increased again. At the time of WCD deployment the oxygen concentration had decreased from approximately 14 % to 6 % in 20 s. Within 40 s after the the WCD was deployed, the oxygen concentration was near 1 %. The oxygen began to increase again after the window sprinkler was activated. As the oxygen decreased, the carbon dioxide, carbon monoxide and total hydrocarbons increased. The carbon dioxide peaked at approximately 17 %, the carbon monoxide at almost 6 % and the total hydrocarbon at approximately 11 %.

The trends, the minimum concentration of oxygen and the peak values of carbon dioxide and carbon monoxide in Figure 5.4.7-3 are similar to the measurements from the upper position.

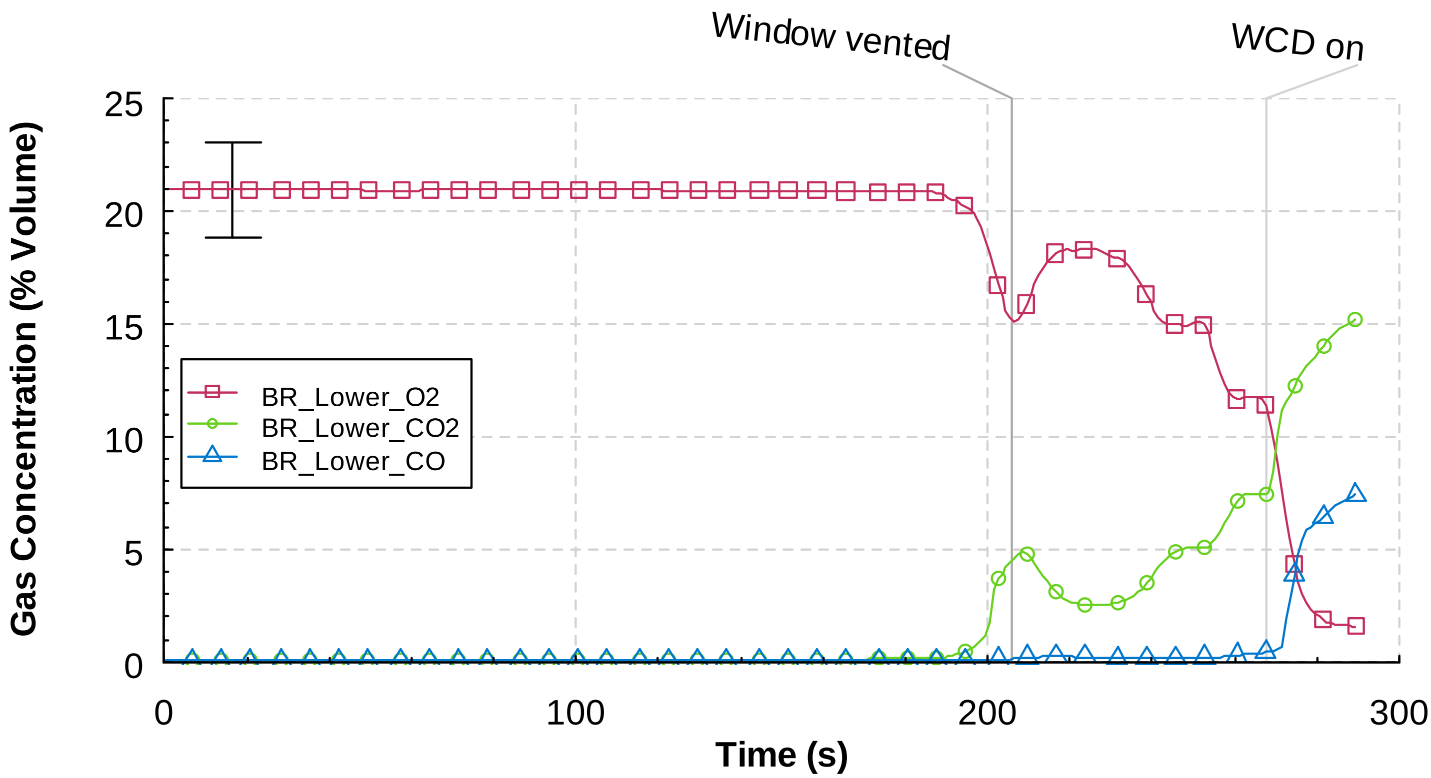

Figure 5.4.7-1. Oxygen, carbon dioxide, and carbon monoxide percent volume versus time from the lower bedroom (BR) sampling location, Experiment 4.

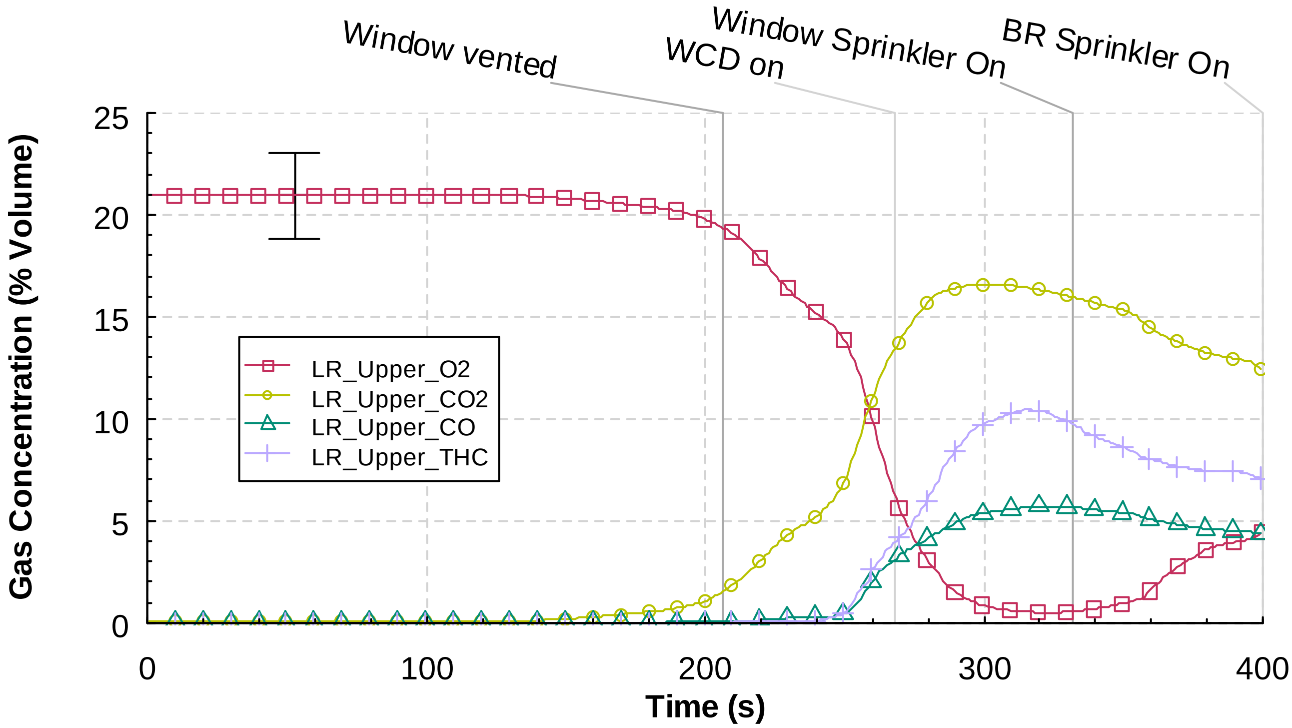

Figure 5.4.7-2. Oxygen, carbon dioxide, carbon monoxide, and total hydrocarbon percent volume versus time from the upper living (LR) room sampling location, Experiment 4.

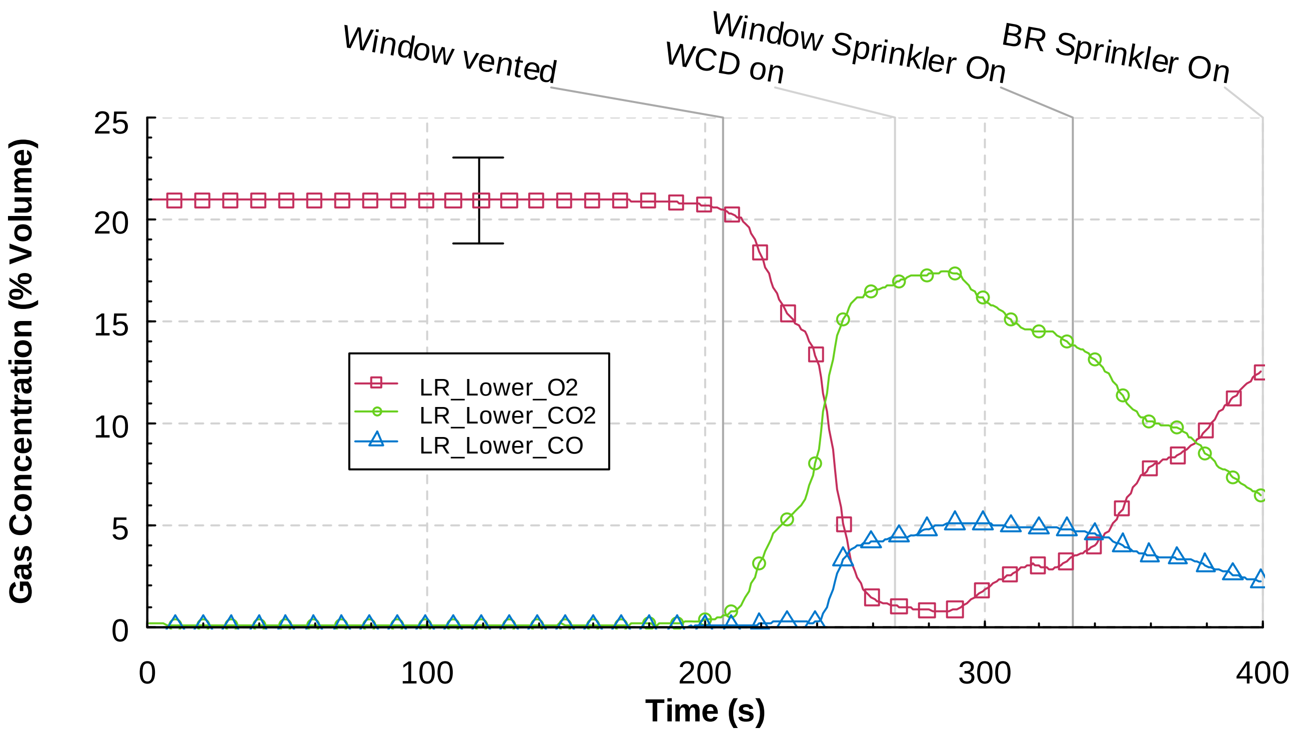

Figure 5.4.7-3. Oxygen, carbon dioxide, and carbon monoxide percent volume versus time from the lower living room (LR) sampling location, Experiment 4.