FIRE PROTECTION
& BUILDING CODE
ENGINEERS • SINCE 1986

TEST ANALYSIS REPORT FOR:

BARRIERTEK FULL-SCALE BURN DEMONSTRATIONS NISKU, ALBERTA

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1. INTRODUCTION

Fires that occur during the course of construction in wood buildings can present a substantial risk to property and adjacent structures largely as a result of the incomplete nature of the fire protection measures normally required in a completed building. Active protection elements such as sprinklers are not often feasible in freezing climates, while passive elements such as gypsum wallboard used in fire separations typically needs to be installed once a structure is weather-tight in order to limit water damage and mold growth. Combined with the exposed wood framing elements, the overall limited nature of fire protection features creates conditions whereby a fire can rapidly spread throughout a large portion of an incomplete structure. This rapid spread limits the potential opportunities for fire departments to be notified, respond, and subsequently enact suppression efforts to protect the involved structure or adjacent properties.

Intumescent coatings offer an opportunity for risk mitigation during construction as a result of their relative ease of application, demonstrated effectiveness in certain standard test methods, and in the cases of durable coatings, their ability to withstand cold weather and exterior weathering. In particular, because the treatments can withstand exposure to the elements for some time until the permanent fire protection features are incorporated into the building, intumescent coatings can provide protection to exposed lumber while dovetailing into the construction methods used for mid- and low-rise combustible construction without requiring complex temporary measures requiring future removal.

In order to evaluate the effect of a BarrierTek intumescent treatment on fire development within a controlled environment, an experimental design was prepared. The focus of the experiment was the relative performance of a treated building in contrast with a building that consists of fully exposed lumber, typical of standard construction. The experiment consisted of two equivalent, three-storey wood structures that were fully framed and sheeted; one of which included BarrierTek intumescent coating on the interior wood surfaces.

Controlled fuel packages were placed into each building and ignited. Sensors positioned throughout the buildings monitored temperature and heat flux. In both cases, the fires were allowed to burn without suppression being applied until the building became fully-involved.

The objective of the testing was to examine the effect of the intumescent treatment by evaluating if ignition of the structure occurred, how the fire within the structure progressed and, the fire dynamics within the first storey of the building. The results of the experiments were related to the radiation emitted out towards heat flux gauges positioned at known distances from the buildings.

2. BACKGROUND

2.1. CODE REQUIREMENTS AND GUIDELINES

Current codes, standards, and best practice documents outline methods builders can implement to reduce the risk presented by the structures during construction. However, few means exist to quantitatively assess whether or not the protection measures provided on a given site are adequate. The 2015 National Fire Code, Article 5.6.1.2 requires that measures be implemented to protect adjacent structures.

> *Protection shall be provided for adjacent buildings and facilities that would be exposed to fire originating from buildings, parts of buildings, facilities and associated areas undergoing construction, alteration or demolition operations. (See Note A-5.6.1.2.(1).)*

The appendix note for Article 5.6.1.2 then clarifies the following:

> *Methods and materials used to protect adjacent buildings and facilities can range from active to passive systems such as spatial separation, installing water curtains, using construction methods and materials that include gypsum sheathing, or erecting a temporary fire barrier such as a fire tarpaulin.*

Given the wording in the appendix reference, it is clear that protection measures are to be incorporated as part of the construction project, and do not support overreliance upon fire department intervention, in particular to control the fire within the building under construction. In order to limit damage to adjacent properties, fire crews will often adopt defensive tactics at a construction site, allowing the fire to run its course within the initial structure while managing the risk of fire spread to neighboring buildings. Given these tactics, measures to protect the structure and adjacent buildings should be incorporated into the design and planning of the project.

The acceptable solutions and the associated Fire Code appendix do not provide substantive detail for use to evaluate if the provided level of protection should be considered adequate. Robbins and Calder reviewed existing codes and practice guidelines within Canada and created a fire safety concepts tree to evaluate where current mitigation approaches exist[1]. This framework identified that:

The construction regulations and occupational health and safety regulations are narrow in their focus relative to the breadth of the fire safety tree concepts. The fire regulations are more broadly applicable relative to the fire safety concepts tree; however the focus is still weighted towards the concepts of "Awareness and Ability" (especially through the element of "Construction Process And Procedure), "limit amount exposed" (particularly for element of "Limit Unauthorized Access" and, "control fuel" (particularly for the "Housekeeping/Waste" element.

This conclusion is consistent with the background research conducted for this experiment. With emphasis placed on measures to prevent ignition and consequence mitigation limited to fire department-related features, gaps are apparent which can reduce the risk of exposure in areas with more challenging response and where rapid deployment of fire department resources may not avoid fire spread to adjacent structures. Increasing the fault-tolerance of protection measures is increasingly important as the overall size and height of combustible construction increases.

[1] Amanda Robbins, Keith Calder, "Comparison of the Canadian Construction Site Fire Safety Regulations/Guidelines", Sereca Fire Consulting, Published by Canadian Wood Council, September 9, 2014.

2.2. INVESTIGATED FIRE DYNAMICS

During the course of construction of combustible buildings, the framed structure presents a significant hazard to adjacent properties in the event of a fire. The absence of permanent fire protection features can often permit a fire to grow rapidly within the framed structure, ultimately exposing the adjacent properties to intense heat, wind-driven flames and brands. Within the structure, fires can spread with relative ease as a result of the generally higher flame spread ratings of wood construction materials, openings within the building, and open nature of the floor plans at the time of framing.

In order to create a comparison between treated and untreated buildings, the experiment was designed to allow for investigation of the following:

- The rate of temperature rise within the building;
- The rate of flame spread up the exterior of the building (as measured by temperature);
- The rate of temperature rise across various assemblies (including a LVL beam and the second storey floor), and;
- Heat flux at the exterior of the structure.

The objective of the measurements between the two buildings was to characterize both the fire growth when the fuel package was the primary fuel source, as well as the differences in these properties once the buildings became involved. Establishing that the fuel packages burned comparably helps control the influence of the ignition source on the growth and spread of the fire. Once ignited using a comparable fuel, the difference between the fire behaviour is then expected to result from the different fire performance of coated versus uncoated lumber.

Inside the compartment, the temperature measurements were intended to record data to evaluate the comparative times to flashover. Standardized tests for wall and surface linings often evaluate the time to flashover in order to establish the influence of the material on fire development. As outlined in the 5th Edition of the SFPE Handbook, "different criteria are commonly used to define flashover: for example, upper layer temperature of 600°C, flames emerging through the doorway, heat flux to the floor of 20 kW/m^2, heat release rate of 1 MW, and so forth"[2]. In this experiment, sensors were positioned to assist in evaluating those metrics which could be feasibly measured within the scope of the experiment. Heat flux within the buildings was not measured, as the untreated building sensors were expected to be destroyed during testing and structural collapse. Similarly, accurate measurements of heat release rates were not feasible. Therefore, measurements of temperatures and physical observation and recordings were deemed to be most suitable for this application.

Heat flux measurements were obtained outside the structure in order to facilitate an understanding of the difference between treated and untreated buildings on one of the more commonly used benchmarks for adjacent property protection: radiant heat flux received by a target assembly. In general, fire protection via spatial separation is premised on the concept that with sufficient distance, a target material exposed to a fire is sufficiently unlikely to ignite, thus providing adequate protection.

The critical heat flux of a material is generally defined as the minimum required heat flux for a material to be ignited. Essentially, this property helps understand possible thresholds that could be applied in order to anticipate whether or not a given material will ignite after a period of time. For example, critical heat fluxes of various natural materials and some plastics range between 10 kW/m^2 and 15 kW/m^2. NFPA 80A "Recommended Practice for Protection of Buildings from Exterior Fire Exposures" uses a heat flux value of 12.5 kW/m^2 as default for its assessment procedure. This value is also used within the spatial separation tables used in the National Building Code of Canada.

The experiment was intended to collect data using Gardon Gauges as targets in order to evaluate and compare the heat flux data obtained between a treated and untreated building. Using this comparison, it would be feasible to understand the relative influence of the coating on the rate of rise, the peak

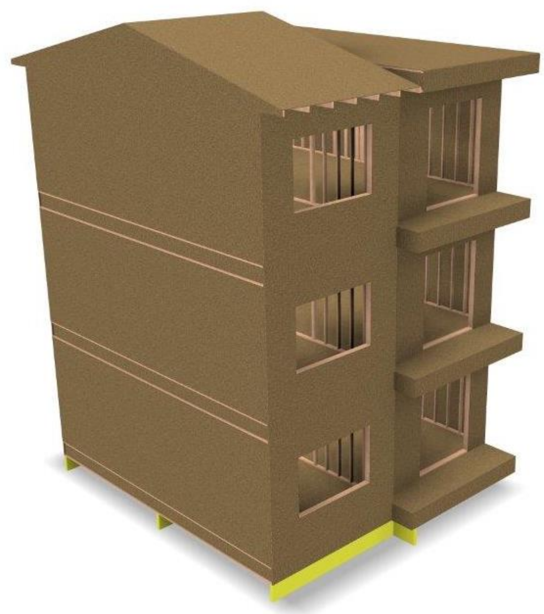
[2] Society of Fire Protection Engineers, "SFPE Handbook of Fire Protection Engineering Fifth Edition", Page 936.

heat flux, and the duration of that peak heat flux to better quantify and establish the effectiveness of the coating on reducing the exposure severity.

3. EXPERIMENTAL SETUP

3.1. BUILDING CONFIGURATION

The test buildings used in the experiment consisted of two identical structures: one treated with an intumescent coating, while the other remained untreated. The floor plans of each storey were intended to represent commercially typical single-bedroom layouts which included a bedroom, closet, bathroom, kitchen/dining area and a living room. Interior stud walls were installed, but were not boarded with gypsum, and therefore, the storeys were essentially representative of a building under construction that was nearing completion of the framing stage [**Drawing 1 & Photo 1**].



Drawing 1 – Rendering of the experimental building.

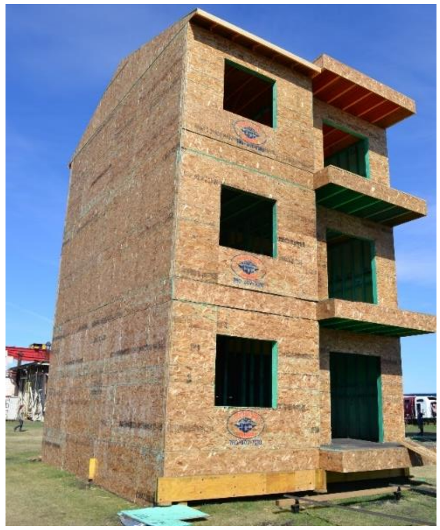


Photo 1 – Photograph of the treated experimental building.

The building area was 64.6 m^2 and each storey had an equal footprint. The height from the top of the subfloor on a given storey to the underside of the sheathing of the storey above was approximately 3.0 m. The total building height was approximately 10.80 m as the building was elevated off the ground using piles and structural elements which raised the level of the first storey's floor approximately 1.06 m above ground level. The bill of materials was used to calculate the average fuel density of the structures. The total mass of the structures was estimated to be approximately 11,000 kg. Across the three storeys, 64.6 m^2 each in area, the average fuel loading of the structures was approximately 57 kg/m^2 (11.7 lbs/ft^2), which aligns with historical considerations for the contribution of combustible construction to the fuel loading of a building.

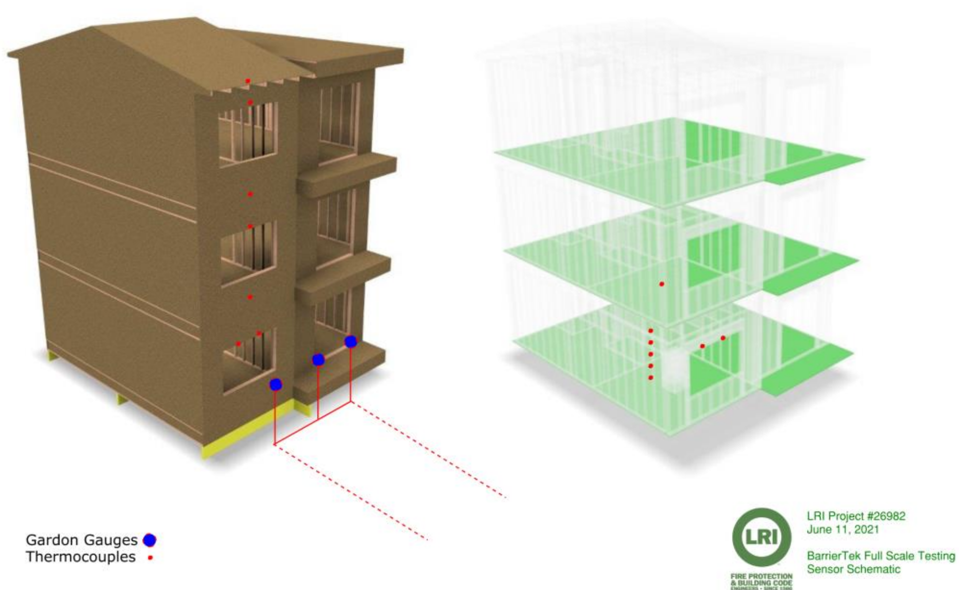
A floor opening approximately 1.0 m^2 was cut near the bathroom at the rear of the structures to represent an opening between the storeys that could exist for material handling or to act as a stairway during construction.

The following materials were used during the construction of each building. The only difference between buildings were that the lumber used in the treated building was coated with BarrierTek coatings using their typical manufacturing processes. In the intumescent treated building, the coatings included the ProTEKtor II system coating the underside of the subfloor, the inside face of the sheathing, I-joists and dimensional lumber, with AtTEK coating on the trusses and roof sheathing at Level 3.

Material	Description
Floor sheathing	29 mm (1 1/8") SPF plywood
Studs	38 mm x 89 mm (nominal 2 x 4) SPF
Engineered Joists	406 mm deep, 64 mm x 38 chords, 9 mm webs (16" deep, 2 ½" x 1 ½" chords, 3/8" webs)
Beams	2 x 44.5 mm x 406 mm (2 x 1.75" x 16") 3100Fb LVL
Trusses	Open wood trusses using 38 mm x 89 mm (nominal 2 x 4) chords and webs/runners
Wall sheathing	12.5 mm (1/2") oriented strand board

3.2. SENSORS AND SENSOR POSITIONING

Sensors were positioned within and in front of the structures. Type K thermocouples were used for monitoring temperature, while Hukseflux Gardon Gauges were positioned outside the structures to monitor heat flux emanating from the buildings. 16 thermocouples were used in each structure, with three Gardon Gauges positioned across the front of the structure mounted to a repositionable sled [**Drawing 2 & Appendix B**].



Drawing 2 – Sensor position schematic [Appendix B], LVL sensors not shown.

The thermocouples were positioned as follows:

Five thermocouples mounted to a steel rack located behind the fuel package. Each probe tip was positioned in free air off of the support structure at the following heights (as measured from the floor): 0.55 m, 1.10 m, 1.65 m, 2.20 m, 2.75 m. The uppermost probe was positioned at approximately the underside of the joists, but was not placed in contact with the joist.

One thermocouple was placed on the top surface of the second-storey floor, inside the bedroom, approximately positioned above the fuel package and covered with a layer of ceramic fibre insulation.

Three thermocouples were inserted into holes drilled into the two-ply LVL beams. Two sensors were positioned at a depth of approximately 100 mm (4”) from the bottom of each LVL. The sensors were positioned approximately centred within each 1.75” thick LVL ply. A third sensor was positioned at approximately the midpoint of the beam, at 8” of depth, within the LVL layer which faced away from the fuel package.

Two thermocouples were positioned across the bedroom window header at approximately one third and two thirds of the width of the window.

Five thermocouples were positioned on the surface of the exterior wall sheathing positioned vertically above the bedroom window. One sensor positioned above each window, one positioned 1.0 m above each the first and second windows, and one at the upper soffits in the attic.

The Gardon Gauges were positioned as follows:

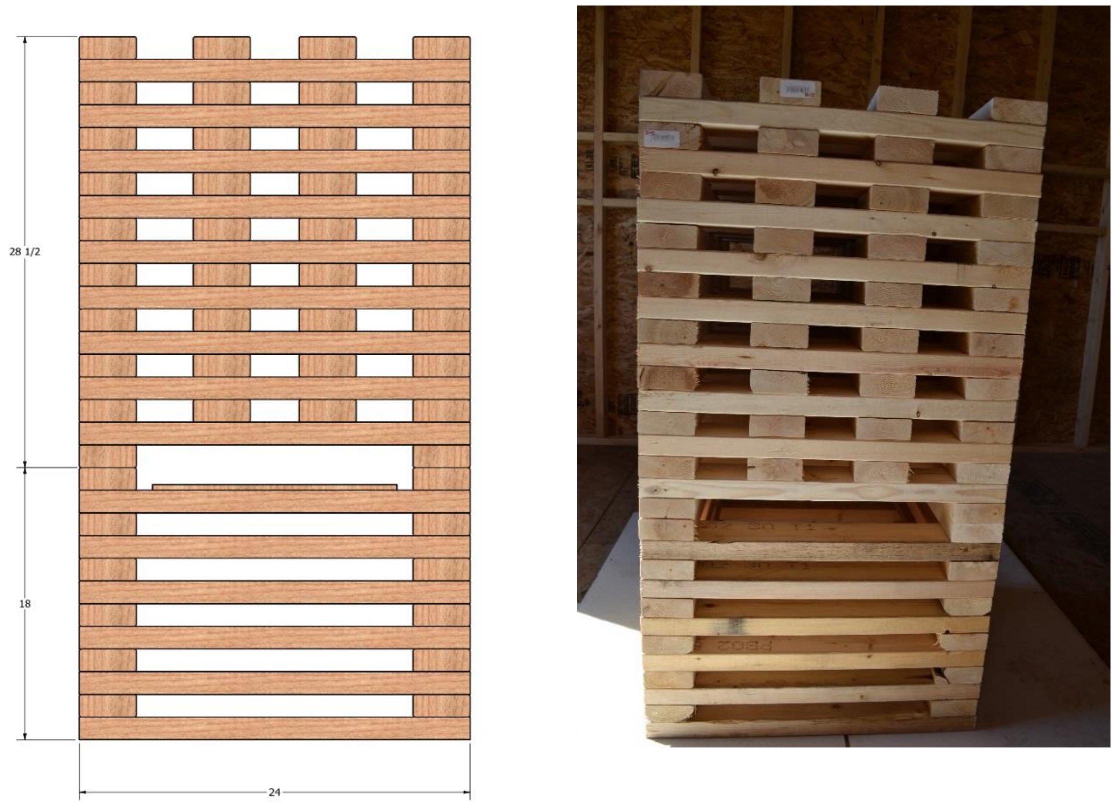
Three sensors on vertical supports which were mounted onto repositionable sleds [**Photo 2**]. The central sensor was approximately centred on the building. The two side sensors were each positioned 1.7 m away from the central sensor. The resulting coverage had a sensor located at approximately 25%, 50% and 75% of the width of the building.

Photo 2 – Gardon Gauges mounted to the sleds.

The use of a repositionable sled permitted the gauges to be moved during the testing as the measured heat flux reached the maximum capacity of each gauge in order to prevent sensor damage. The initial sensor placement placed the row of gauges 1.2 m from the front of the building face. Markings for second positions were located 2.4 m from the building face and 3.6 m from the building face. The time when the sled was moved was recorded in observation notes.

3.3. FUEL PACKAGE AND FIRE DYNAMICS

The fuel packages for each structure were constructed using nominal 2 x 4 spruce pine fir (SPF) dimensional lumber arranged in a regular array (wood crib). Each crib consisted of 18 layers, with four sticks per layer. Each stick was cut into 610 mm (24”) lengths, and was spaced approximately 89 mm (one stick width) apart. The overall dimensions of the wood crib was 610 mm wide, 610 mm long, and 686 mm tall [**Drawing 3**].



Drawing 3 – Wood crib used for the initial fuel package.

The mass of wood in the crib was 68 kg. The average moisture content of the wood on the day of the testing was 6.5% in the treated building and 7.1% in the untreated building.

The cribs were ignited using two aluminum tins containing approximately 50 ml of methyl hydrate placed onto a platform below the cribs.

The platforms consisted of 13 layers of nominal 2 x 4 lumber cut into sections, but with only two sticks per layer supporting the wood crib above. The combustibility of the platform was anticipated to add nominal fuel during the earliest stages of the combustion as a result of its position below the wood crib, however during the experiment it was observed that brands from the cribs above fell and ignited the wooden platforms approximately 16 minutes after ignition.

The use of wood cribs was intended to permit a greater degree of uniformity and consistency between each test burn. Absent data from a cone calorimeter, wood cribs represent well-studied fuel packages which can produce relatively consistent fire dynamics which can be reasonably well-controlled and tailored to assess specific engineering concerns. Based on the crib geometry, the fuel surface and crib porosity would limit the combustion at the earliest stages of the fire to between approximately 350 kW and 525 kW. Based upon the apparent flame heights while the wood cribs were burning (without igniting the platforms), the anticipated heat release rate was approximately 500 kW assessed by applying the Heskestad correlation based on an approximate flame height of 2.1 m from the base of the fire, and an effective crib diameter of 688 mm.

The fuel packages were selected based on their ability to produce repeatable results, consistent burning, and more easily assessed combustion behaviour. As the experiments were not intended to replicate a particular ignition scenario, selecting a design fire based on hypothetical contents or fuel distributions was not pursued. The objective of the fuel package sizing was to permit flames to reach from the fuel package and impinge upon the joists and ceilings above. By positioning the fuel packages relatively centred within the rooms, the ignition of the structures was isolated to ceiling-specific fire dynamics thus limiting the initial impact of vertically oriented fuels such as wall sheathing or studs. Moreover, by implementing a moderately sized fire, the ignition of both structures would be delayed as compared to larger fires which might ignite the structures while continuing to grow, thus theoretically influencing the overall compartment dynamics in a less controlled manner and impacting the resultant conclusions. This methodology appears to have worked effectively in the untreated building, as the structural fire visually exceeds the amount of flames produced by the initial fuel package very quickly after ignition of the joists.

4. DATA ANALYSIS

In order to analyze the data and compare both buildings, raw data input from the data logging system was exported and reviewed in conjunction with the field observations and notes taken during each test. The data logging systems were initiated and recording data in advance of the ignition. The charts below compare each experiment based on the ignition times. In each case ignition occurs at 0.0 s in the charts.

The following actions or observations were noted:

BarrierTek treated building:

Observation	Time (s)
Ignition	0
Crackling heard from fuel package	43
Flames observed at fuel package	130
Flames growing to ceiling level as observed through front window	458
Continued burning with flame impingement at ceiling	565
Reduction in apparent fire size	1418
Suppression of fuel package begins	1950
Suppression complete	2120

Untreated building:

Observation	Time (s)
Ignition	0
Flames observed at fuel package	326
Flames growing to ceiling level as observed through front window	478
Charring of the bottom chord of the joist	540
Joists above fire ignite	1440
Flames begin to extend out front wall	1498
Gardon sled moved to 2.4 m	1505
Gardon sled moved to 3.6 m	1529
Flames spread across front façade	1533
Venting visible from attic	1548
Gardon sled moved to approximately 5 m	1550
Water is applied to structure	1626
Roof begins to collapse	1751
Roof and third storey wall collapse	1848
Gardon gauges retracted to rear of assembly	1910
Structure collapses	1931

4.1. THERMOCOUPLE TREES

The thermocouple trees demonstrate the stratification of the compartment of origin local to the fire. As outlined in Section 3.2, the thermocouples were located at various heights behind the fuel package. Understanding the temperature growth within the compartment can provide insight into the comparison between initial fuel package behaviours, as well as when more substantial changes occur, such as when the building begins to contribute to the fire. [**See Figures 1 & 2 in Appendix A**]

Notable observations relative to the thermocouple trees included:

- Upper layer temperatures at 2.20 m above the floor rose from ambient to approximately 100°C at approximately the same time 840-1020 s after the ignition of the fuel package. This is consistent with the expected results due to the comparable geometry of the structures combined with the standardized fuel package [**Figure 3**].
- Notable divergence occurred between the uppermost layer temperatures as recorded by the top thermocouples is unexpected, but may be related to sensor positioning relative to the fuel package and wind.
- The upper layer temperature in the treated building appears to have exceeded that in the untreated building.
- The uppermost thermocouple in the untreated building appears to fall off the support as the building caught fire.
- The next-uppermost thermocouple reached approximately 600°C at 1498 s. This occurred 58 seconds after observing the initial ignition of the joists. The temperatures at this thermocouple began to rapidly increase at 1458 seconds as the building began to ignite.
- The treated building's uppermost two thermocouples did not exceed 250°C at any point in the experiment.

4.2. EXTERIOR THERMOCOUPLES

The exterior mounted thermocouples were positioned in a comparable manner to other experimental studies and methods used to evaluate the fire performance of exterior wall assemblies. The objective of the exterior thermocouples was to establish the rate of fire growth up the exterior wall. Evaluating the temperatures combined with visual observations allows a better understanding of the difference between a treated and untreated building with respect to fire growth outside the structure. This value helps to more quantitatively establish the impact of the coating on fire growth at faces which would be exposing building faces. [**See Figures 4 through 7 in Appendix A**]

Notable observations relative to the exterior thermocouples included:

- Gas temperatures at the window header in the bedroom in front of the fuel package was consistent around 115-140°C between both buildings until the ignition of the untreated building occurred at 1440 s. This supports that a comparable level of heat loss through convection and ventilation as the temperatures and wind speeds were comparable during both fires [**Figure 5**].
- The vent temperature of the untreated building increased to approximately 600°C at approximately the same time (1496 s) after the ignition of the fuel package, consistent with the ceiling gas temperatures noted above.
- A maximum vent temperature of 945°C was achieved prior to water application.
- Temperatures up the side of the untreated structure increased rapidly; attic temperatures of 700°C were reached at 1608 s, within three minutes of the onset of structural involvement in the fire, and under two minutes from flames venting through the first storey window [**Figure 7**].

4.3. GARDON GAUGES

Gardon gauges were used to measure the heat flux from both buildings at specified distances. This allows for both a comparison of the equivalency of both fires in the earliest stages of fire growth, but also to establish realistic heat flux values of large exposed construction building faces. To avoid damaging the gauges, they were mounted onto sleds to permit them to be retracted once the buildings began to be fully-involved.

As outlined in Section 3.2, the initial position of the gauges was in a horizontal row positioned approximately mid-height up the window at the front of the structure. The initial position was 1.2 m away from the building face, the second position was 2.4 m away, and the third position was 3.6 m away. The heat flux gauges in the treated building did not have to be moved due to the overall lower peak intensity of the fire. The gauges on the untreated building needed to be retracted past 3.6 m as the building became fully-involved and began collapsing. [**See Figures 8 through 11 in Appendix A**]

Notable observations relative to the Gardon Gauges included:

- The heat flux recorded by both gauges positioned in front of the bedroom windows were comparable until 1450 to 1460 s when the untreated building began to ignite [**Figure 10**].
- The maximum heat flux from the fire within the treated building was generally about 2 kW/m^2.
- The heat flux at the point when the untreated building began to ignite was approximately 1.6 kW/m^2.
- The heat flux across the gauges on the untreated building reached 12.5 kW/m^2 at approximately 1490 s when the gauges were 1.2 m away from the building face.
- The heat flux across the gauges on the untreated building exceeded 25 kW/m^2 at 1499 s when the gauges were 1.2 m away from the building face immediately prior to them being moved back at 1505 s. The gauge nearest the bedroom window reached a heat flux of 70 kW/m^2 prior to being pulled back.
- The gauges were remained at the 2.4 m distance for 24 s before being pulled back further to the 3.6 m mark. They remained at 3.6 m until 1550 s. The peak heat flux at 2.4 m was 26.8 kW/m^2. The peak heat flux at 3.6 m was 28 kW/m^2 at 1552 s at approximately the time they were moved further back [**Figure 11**].
- These significant heat flux values were measured approximately two minutes from when the joists ignited.

- A moderate decrease in the average of the three heat flux gauges occurred at approximately 1619 s approximately when firefighting water was applied. The average fluxes prior to this time were 18-20 kW/m^2, whereas after the drop, the recorded average was 10-13 kW/m^2, demonstrating that suppression efforts either reduced the intensity of the fire or provided a measure of protection to the gauges.

4.4. ANALYSIS SUMMARY

Each of the fires inside the treated and untreated buildings generally produced comparable burning behaviour during the initial stages of the fire. When the wood crib was the only fuel contributing to the combustion process, overall, both buildings performed comparably. The 2.20 m upper layer temperatures, vented gas temperatures, and radiant heat fluxes all aligned reasonably well between both cases. This is the expected result where a comparable fuel load is introduced into compartments of equal geometry and comparable weather conditions.

Some divergence was noted in the uppermost layer temperature at 2.75 m above the floor in each building. This difference may be in part attributable to wind speeds that were about 20% higher during the untreated test, however this would not likely explain the entire deviation. Alternatively, the observed difference may relate to sensor positioning and flame tilt, as the flames are visibly tilting towards the front of the building, while the sensors are positioned behind the fuel package. Regardless, the consistency of other thermocouple tree data points, the window header data points, and the heat fluxes recorded out the window are all indicative of comparable fuel package fire dynamics.

Once the untreated structure ignited and began to contribute to the fire, the available fuel load within the structure combined with the relatively higher flame spread rating of lumber allowed the fire to develop rapidly. Compartment temperatures within the first storey reached 600°C within about one minute following the initial ignition of the structural elements. At approximately the same time, internal video feeds from the experiment shows the wood subfloor of the first storey ignite in the areas surrounding the fuel package. Substantial vent burning out the openings also occurs around this time, as the fire spreads up the exterior wall of the building. These observations tend to be consistent with a compartment that has reached flashover.

Fire suppression efforts began on the untreated building at 1626 seconds, roughly two minutes following the apparent flashover of the bedroom compartment. The rapid development of the fire from initial ignition of structural elements to a fully-involved structure demonstrates the high challenge nature of fires involving exposed combustible construction, and supports the concept that using a means to limit the involvement of the building as a primary fuel source offers opportunities to limiting the severity of an accidental fire scenario. By preventing the involvement of the structure while the initial fuel packaged burned, the intumescent coating restricted the degree of damage to the treated structure, and ultimately allowed the fuel package to nearly self-extinguish, thus providing a means of restricting the available combustibles within the treated building.

5. CONCLUSIONS & FUTURE WORK

This experiment studied the impact of BarrierTek intumescent coatings on lumber used to construct a commercially typical layout representing mid-rise residential construction. A comparable fuel package was placed into coated and uncoated example buildings and ignited. Temperature and heat flux measurements were taken inside and outside each structure in order to evaluate the differences between each building that could be attributed to the intumescent coating. In particular, the objective was to evaluate and compare the overall fire severity between both structures, including estimates of the time to flashover, once the buildings ignited.

In this case, the fuel package was unable to ignite the treated structure before essentially self-extinguishing, but ultimately produced data within each building to substantiate that the fuel packages burned in a comparable manner. The untreated building ignited and demonstrated the speed at which a fire can develop in a building under construction. The untreated building provides a baseline comparison dataset for future testing of the BarrierTek coated structure which remained intact. Future testing will be intended to establish comparable performance with larger fires to better demonstrate the size of fire required to cause the building to ignite, and to evaluate how the rate of fire growth is slowed, if a reduced maximum fire severity occurs, or both.

The following observations and conclusions can be drawn from the experiment at present:

- The intumescent coating was effective at limiting the involvement of the building's structural elements in the fire.
- Intumescence was observed on the lumber surrounding the fuel package indicating it had reacted as expected.
- The fuel packages in both the treated and untreated buildings generally performed comparably and produced similar fire dynamics in both cases.
- The ignition of the untreated structure occurred suddenly, with few outwardly apparent changes to the visible portions of the exposed wood.
- Once the structure became involved in the fire, rapid spread and fire development occurred within the untreated structure.
- Qualitative and quantitative indications of flashover within the compartment of origin occurred in the untreated building approximately one minute after the initial signs that the joists had ignited.
- Fire spread out the exterior wall and up into the attic occurred within minutes of the joist ignition.
- Suppression applied once the building became fully involved had some impact on the recorded heat fluxes until structural collapse occurred. Whether the reduction was associated with a reduced intensity of the fire, or reduction in the radiation received at the gauges is not clear.
- The building collapsed within about eight minutes from the ignition of the structure.

Relating these findings back to the objective of evaluating adjacent property protection measures, the following considerations are noted:

- The time between the ignition of a fire and the involvement of the building are challenging to predict and depend on factors such as the peak heat release rate of the initial fuel package, and its orientation within the building relative to additional combustible materials or the building structure itself.
- Given this uncertainty, limiting the possible fire size within the building of origin or limiting the ability of the fire to spread within the structure offers protection to the building under construction and adjacent properties by way of a reduced exposure severity. These protection measures interrupt the fire growth at a critical point in time, as the fire's growth and spread once the untreated building ignited occurred very rapidly with little warning.
- Property protection measures installed outside the building under construction to protect adjacent properties will require rapid setup, activation or deployment in order to provide a useful measure of protection.
- Attempting to reduce the intensity of the fully involved structure offers limited protection to adjacent structures.
- A reduction in radiation intensity occurs when the building of origin collapses, which can occur within 10 minutes of the fire igniting the structure as shown in this case.

5.1. FUTURE WORK

During the course of the experiment and subsequent data analysis, a number of additional data sets and possible experimental tests were identified that would further assist in evaluating the impact of the intumescent product on fire growth and development. Specifically, the additional investigation is anticipated to investigate:

- How large of a fuel package is required to cause a treated building to ignite and begin contributing to the fire growth?
- Once ignited, how do the relevant metrics (compartment temperature, exterior wall temperature, and heat flux) vary as compared to the

untreated building, especially with respect to any effects of delaying fire growth, spread, or the onset of flashover?

- How does the influence of the coatings impact the resultant dynamics of a fire similar to the Room Corner Test?
- How does the structure react to exterior fire spread, including via balconies?
- What is the impact of closures on the fire dynamics, whether these are typical windows, or protection measures installed at rough openings? Can these measures limit radiant heat exposure until the building under construction collapses?

APPENDIX A – FIGURES

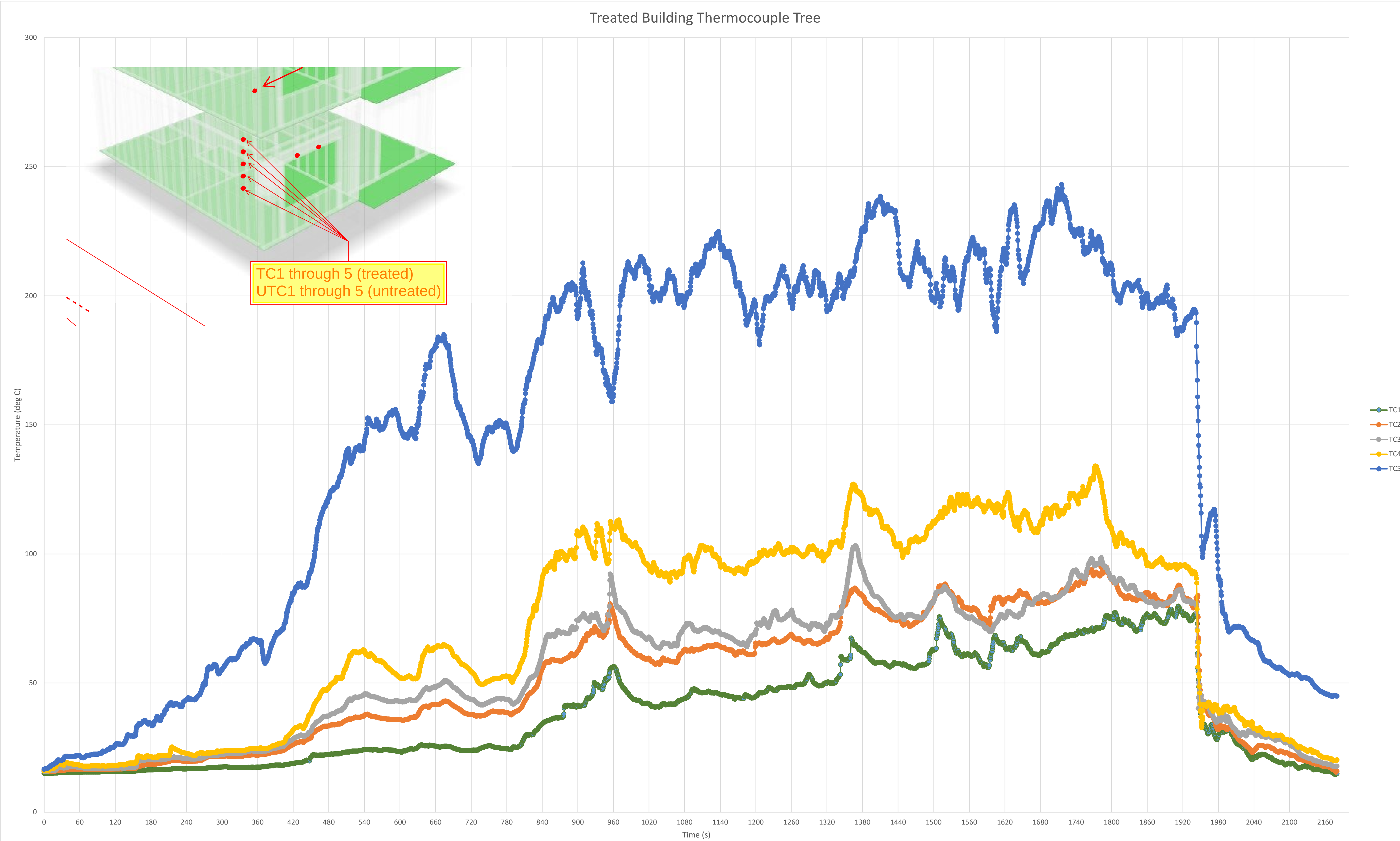
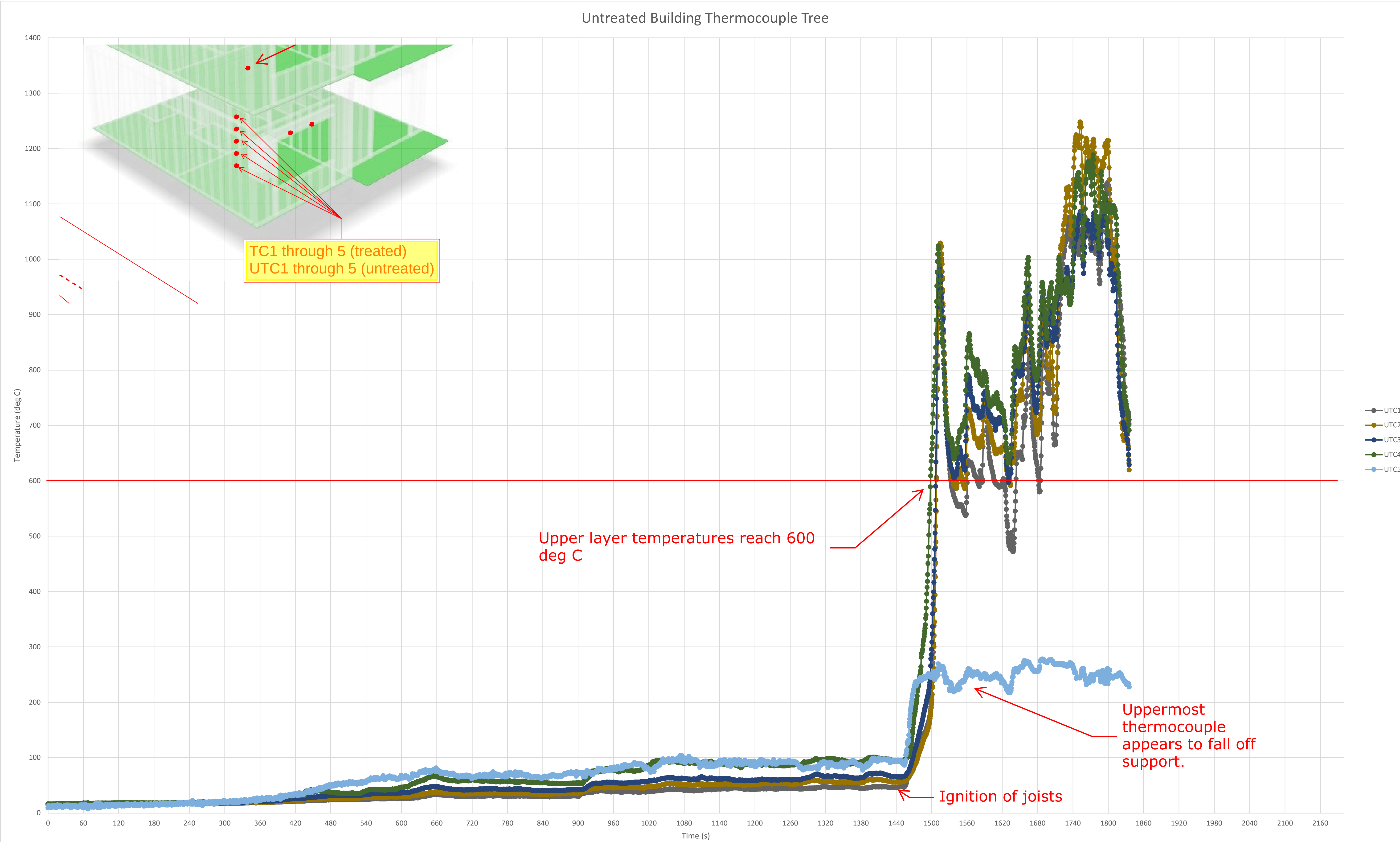

Treated Building Thermocouple Tree
TC1 through 5 (treated)
UTC1 through 5 (untreated)
Temperature (deg C)
Time (s)
TC1
TC2
TC3
TC4
TC5
0
50
100
150
200
250
300
0
60
120
180
240
300
360
420
480
540
600
660
720
780
840
900
960
1020
1080
1140
1200
1260
1320
1380
1440
1500
1560
1620
1680
1740
1800
1860
1920
1980
2040
2100
2160

Figure 1



Untreated Building Thermocouple Tree
TC1 through 5 (treated)
UTC1 through 5 (untreated)
Upper layer temperatures reach 600 deg C
Uppermost thermocouple appears to fall off support.
Ignition of joists
Temperature (deg C)
Time (s)
UTC1
UTC2
UTC3
UTC4
UTC5

Figure 2

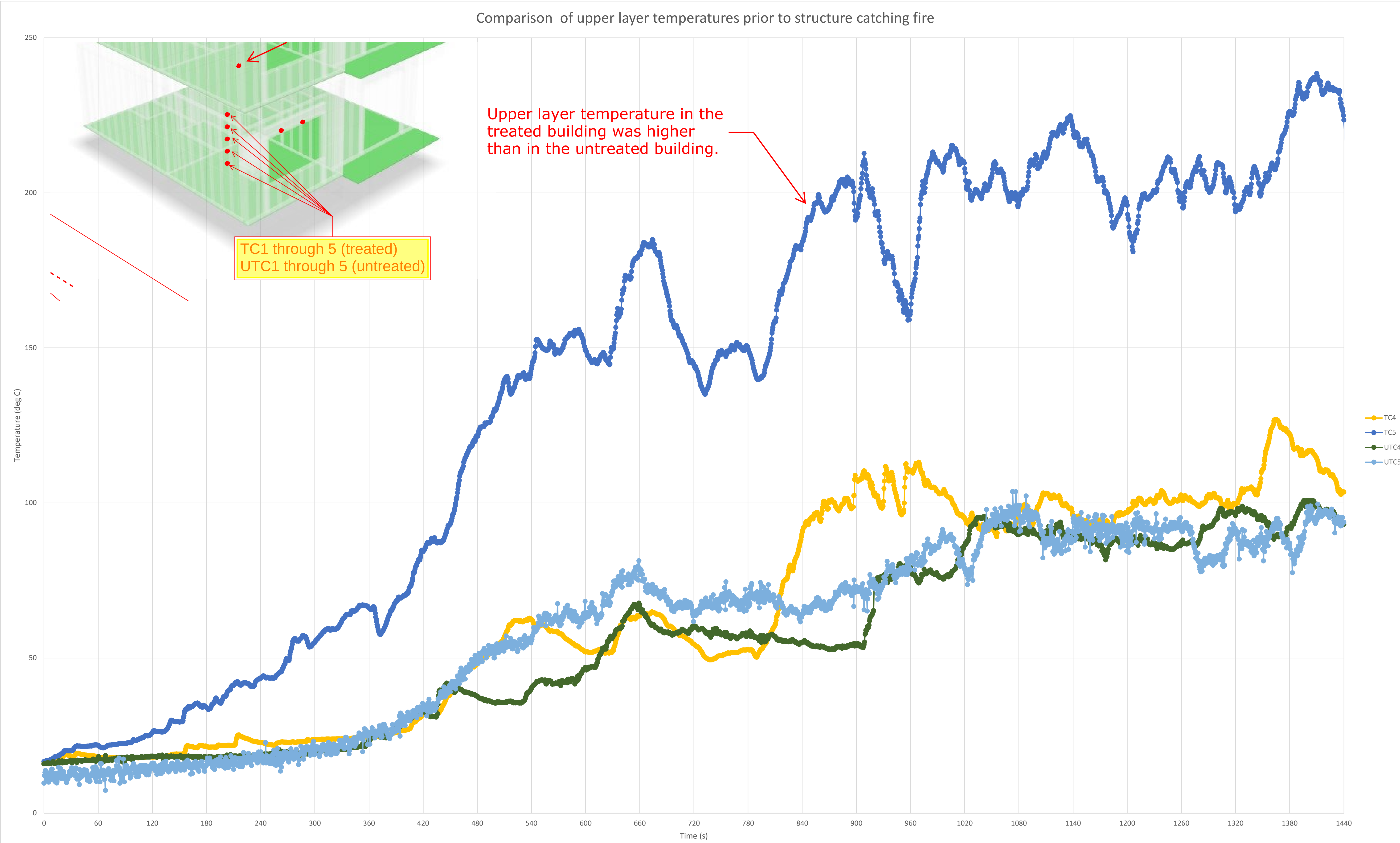
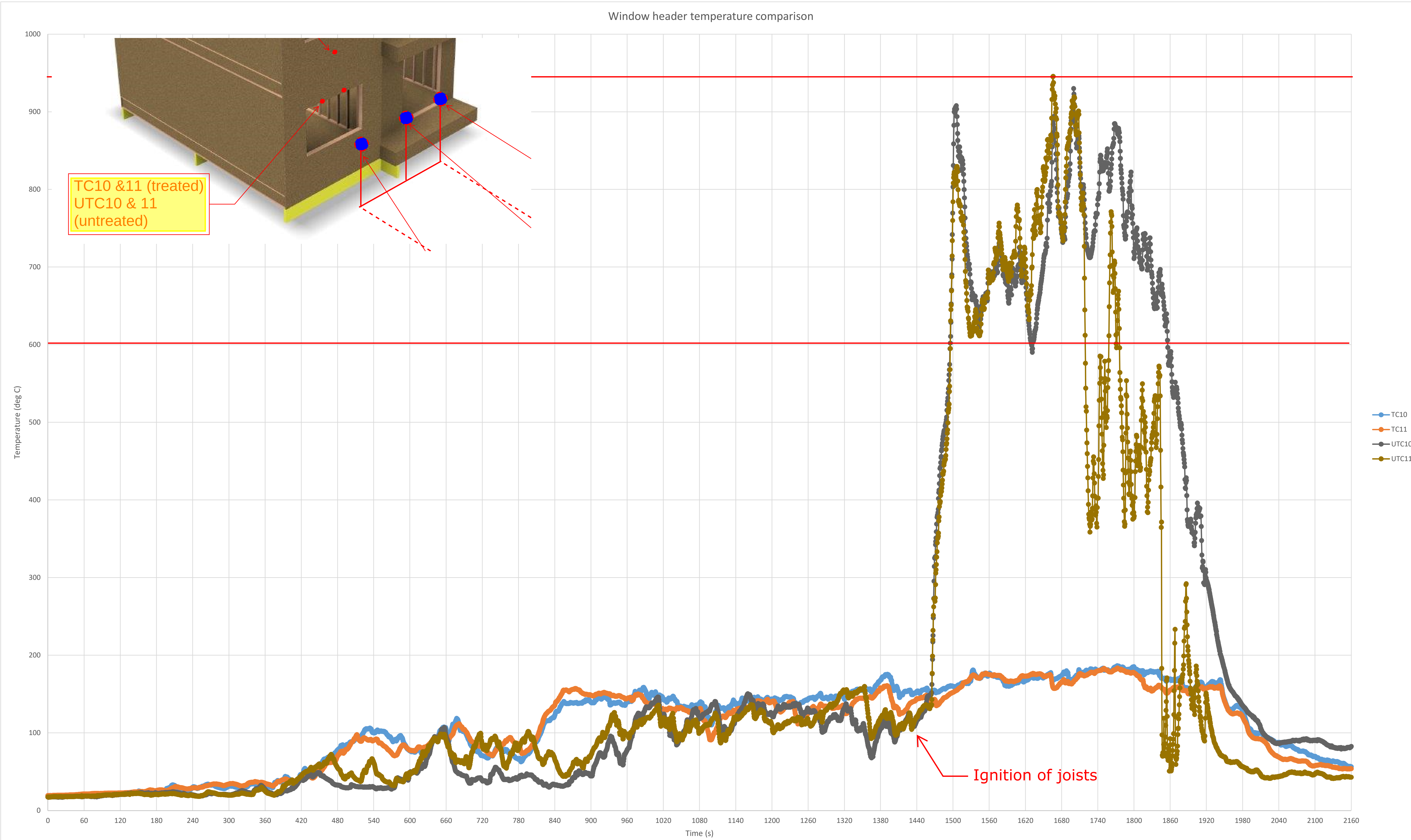

Comparison of upper layer temperatures prior to structure catching fire
Upper layer temperature in the treated building was higher than in the untreated building.
TC1 through 5 (treated)
UTC1 through 5 (untreated)
Temperature (deg C)
Time (s)
TC4
TC5
UTC4
UTC5

Figure 3

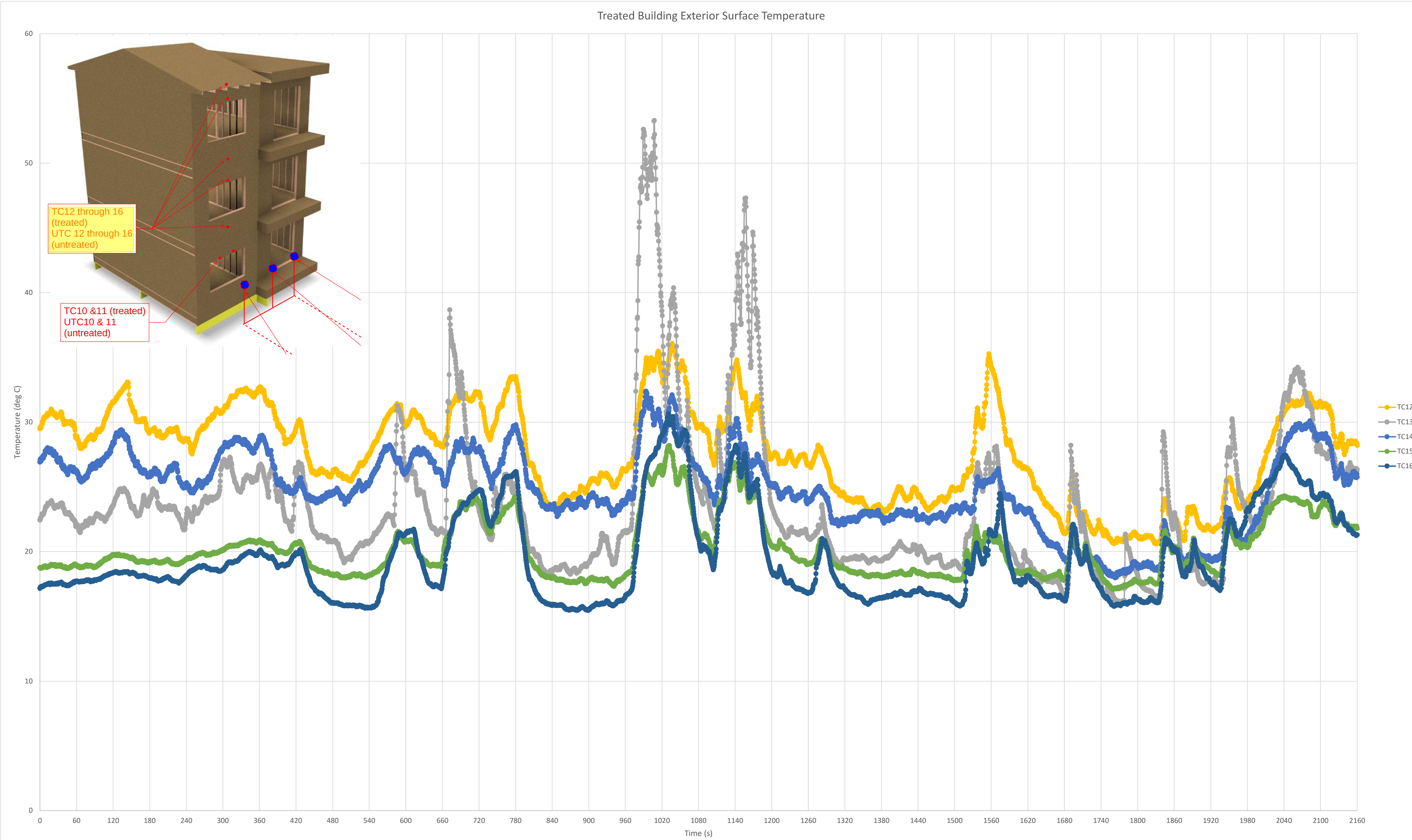


Window header temperature comparison
TC10 &11 (treated)
UTC10 & 11
(untreated)
Ignition of joists
Temperature (deg C)
Time (s)
TC10
TC11
UTC10
UTC11

Figure 4


Window header temperature comparison prior to ignition of structure
TC10 &11 (treated)
UTC10 & 11
(untreated)
Temperature (deg C)
Time (s)
TC10
TC11
UTC10
UTC11

Figure 5



Treated Building Exterior Surface Temperature
TC12 through 16
(treated)
UTC 12 through 16
(untreated)
TC10 &11 (treated)
UTC10 & 11
(untreated)
Temperature (deg C)
Time (s)
TC12
TC13
TC14
TC15
TC16

Figure 6

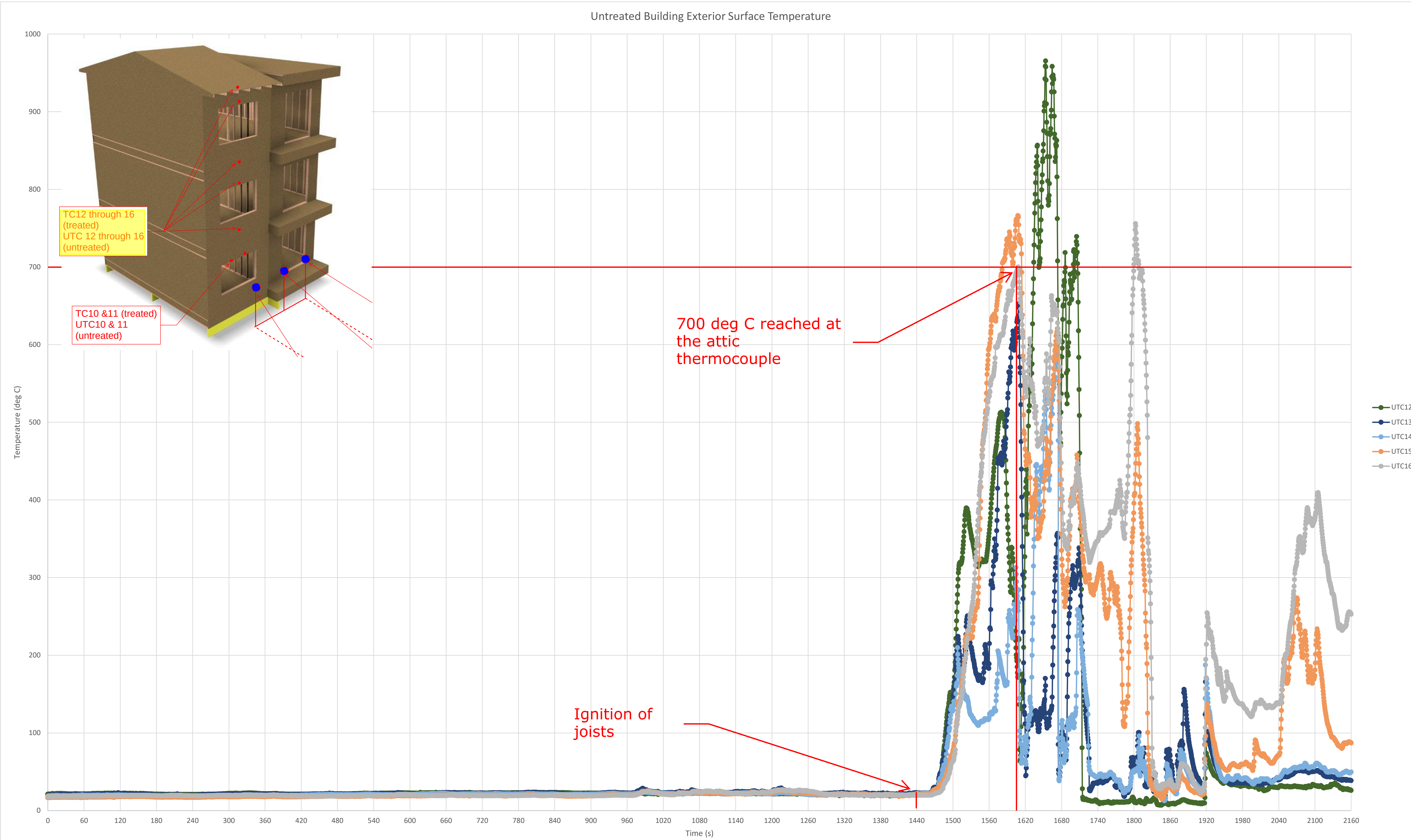
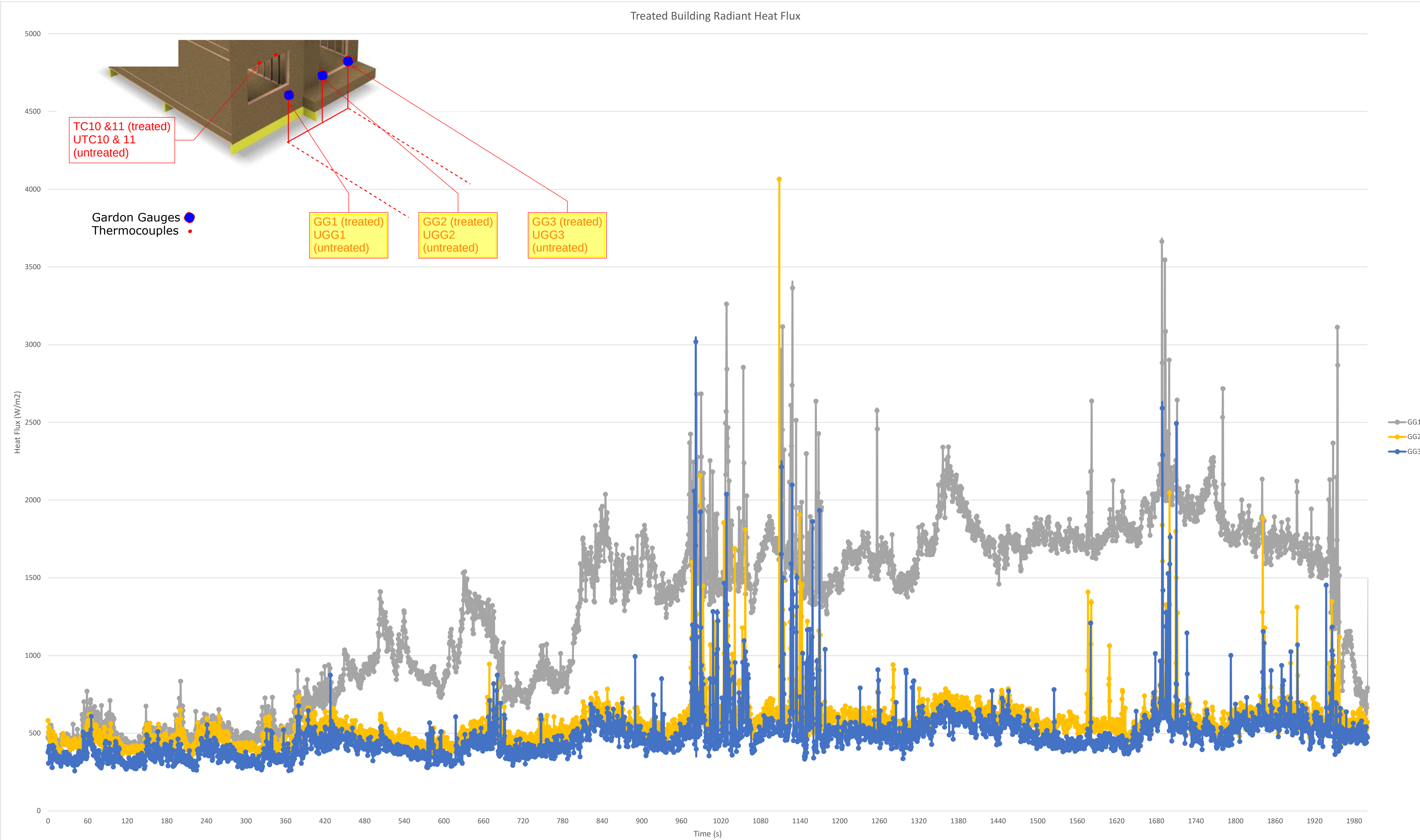

Untreated Building Exterior Surface Temperature
Temperature (deg C)
Time (s)
TC12 through 16 (treated) UTC 12 through 16 (untreated)
TC10 &11 (treated) UTC10 & 11 (untreated)
700 deg C reached at the attic thermocouple
Ignition of joists
UTC12
UTC13
UTC14
UTC15
UTC16

Figure 7



Treated Building Radiant Heat Flux
TC10 &11 (treated)
UTC10 & 11
(untreated)
Gardon Gauges
Thermocouples
GG1 (treated)
UGG1
(untreated)
GG2 (treated)
UGG2
(untreated)
GG3 (treated)
UGG3
(untreated)
Heat Flux (W/m2)
Time (s)
GG1
GG2
GG3

Figure 8

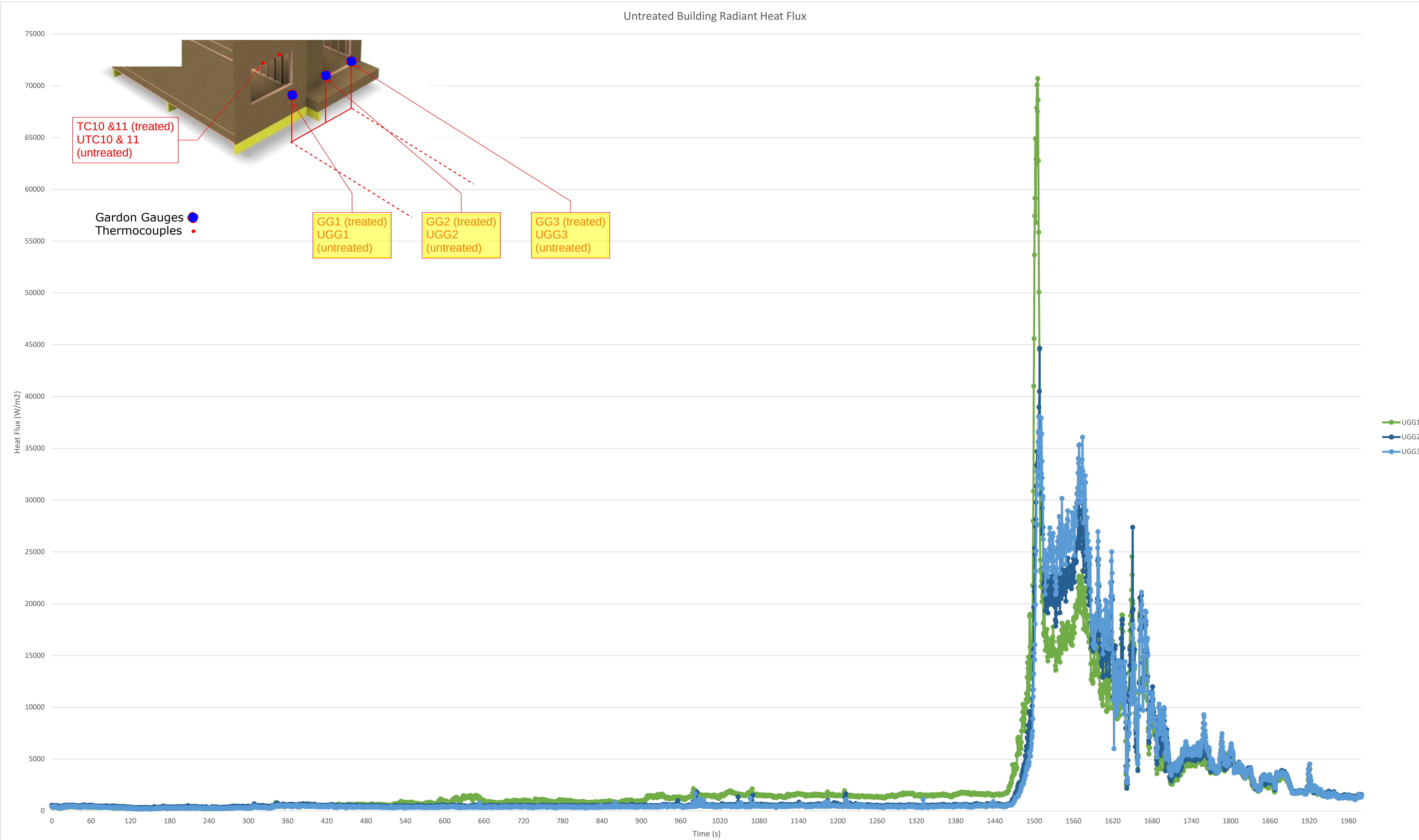

Untreated Building Radiant Heat Flux
TC10 &11 (treated)
UTC10 & 11
(untreated)
Gardon Gauges
Thermocouples
GG1 (treated)
UGG1
(untreated)
GG2 (treated)
UGG2
(untreated)
GG3 (treated)
UGG3
(untreated)
Heat Flux (W/m2)
Time (s)
UGG1
UGG2
UGG3

Figure 9

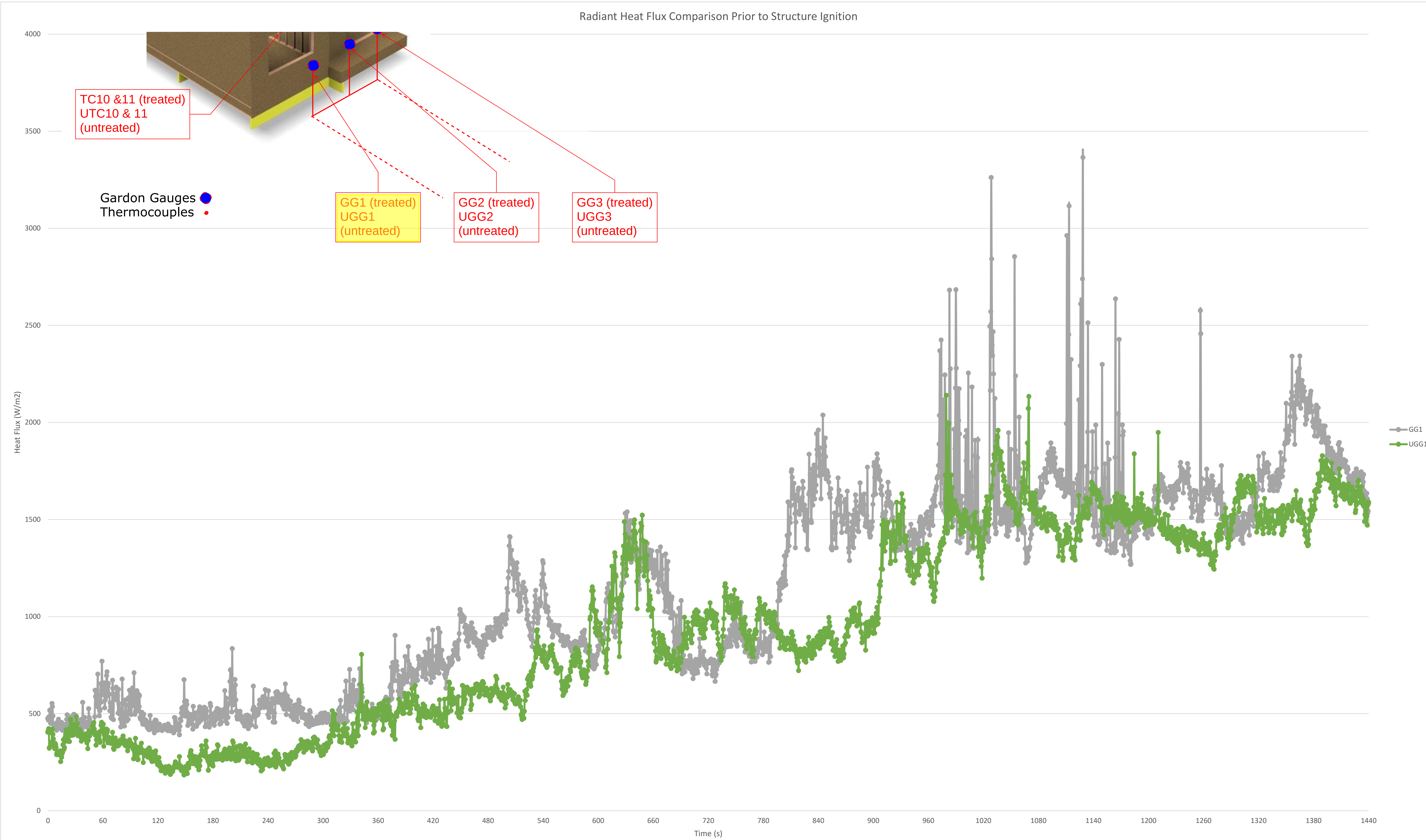

Radiant Heat Flux Comparison Prior to Structure Ignition
TC10 &11 (treated)
UTC10 & 11
(untreated)
Gardon Gauges
Thermocouples
GG1 (treated)
UGG1
(untreated)
GG2 (treated)
UGG2
(untreated)
GG3 (treated)
UGG3
(untreated)
Heat Flux (W/m2)
Time (s)
GG1
UGG1

Figure 10

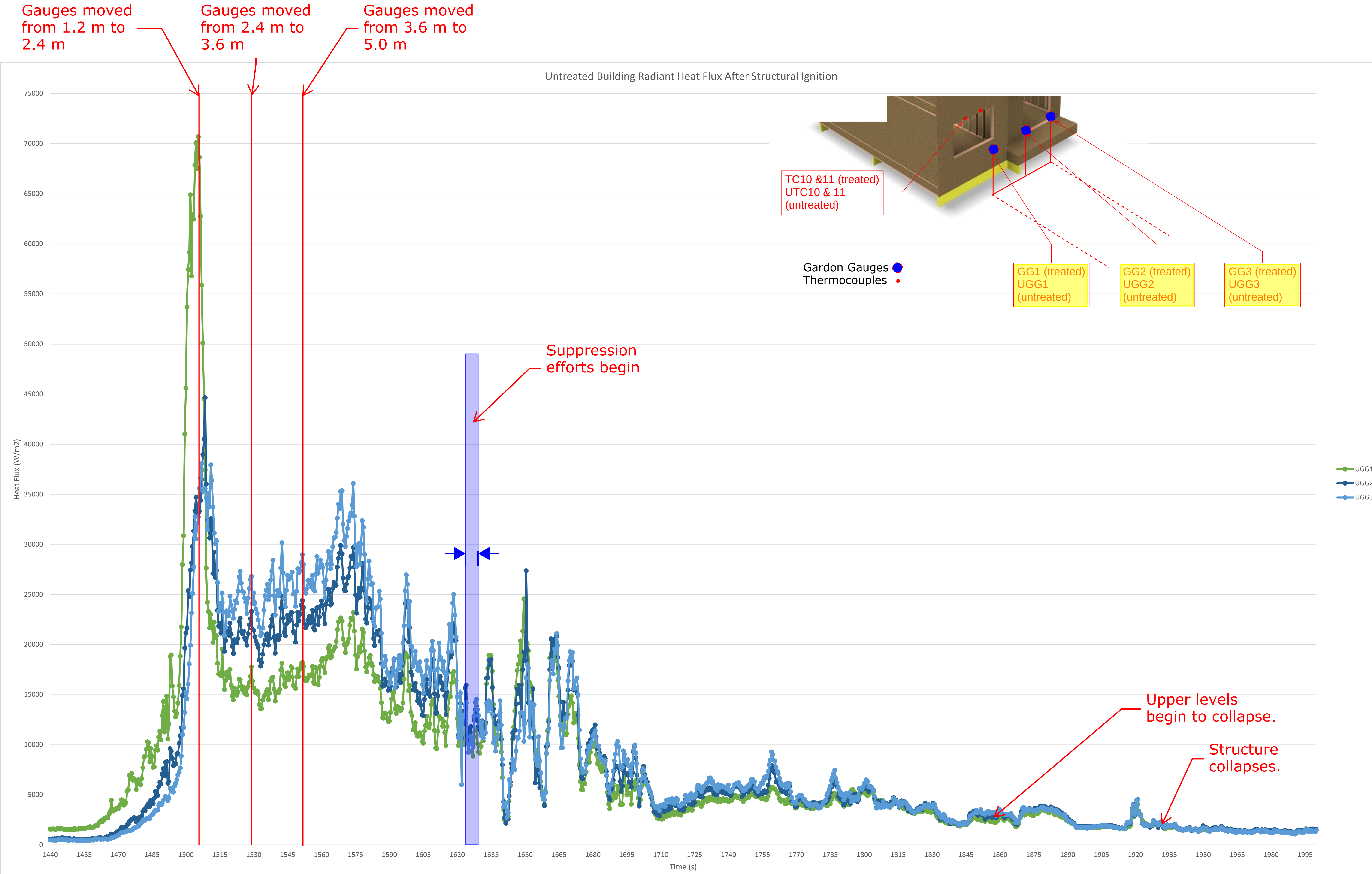

Gauges moved from 1.2 m to 2.4 m
Gauges moved from 2.4 m to 3.6 m
Gauges moved from 3.6 m to 5.0 m
Untreated Building Radiant Heat Flux After Structural Ignition
TC10 &11 (treated)
UTC10 & 11 (untreated)
Gardon Gauges
Thermocouples
GG1 (treated) UGG1 (untreated)
GG2 (treated) UGG2 (untreated)
GG3 (treated) UGG3 (untreated)
Suppression efforts begin
Upper levels begin to collapse.
Structure collapses.
Heat Flux (W/m2)
Time (s)
UGG1
UGG2
UGG3

Figure 11

APPENDIX B – SENSOR PLACEMENT

LRI Project #26982
June 15, 2021

BarrierTek Full Scale Testing
Sensor Schematic