Update: ISU Stave Core QA Reproducibility III: A Review of the Reproducibility Studies

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ISU WEEKLY STAVE QA MEETING
MAY 24, 2018

Motivation

- When measuring the thermal profile of a stave core, the physical qualities of the stave core should not depend on the measurement method. The following presentation shows an attempt to isolate some of the variables that effect thermal profile measurements and see their effects on the reproducibility of the stave core thermal measurements.
- If reproducibility of the thermal stave measurements cannot be easily attained, the measurement of thermal impedance should be thoroughly explored. The thermal impedance of the stave is an intrinsic measurement of the stave, which should be reproducible at any location during QC measurements. This is where it is all going…

Method: General Outline

- Different types of experiments were done changing different variables over different days
  - 1. Simple reproduction. (Attempt to keep all variables the same)
  - 2. Varying the time with the nitrogen off. (Most time spent here)
  - 3. Varying the wait time before measurement.
  - 4. Varying the chiller pump settings
- In each experiment the user can only directly control
  - Set Temperature of the chiller, Booster Pump RPMs, Time waiting, Nitrogen flow rate, Camera measurement

Method: Measured Variables

- Thermocouples(measured every 1 sec in log)
  - T_in: temperature of the fluid going into the stave
  - T_out: temperature of the fluid going out of the stave
  - T_box: temperature floating in the box above the cradle
  - T_room: temperature floating above the table in the room
- Humidity Sensor(measured every 10 secs in log)
  - Humidity: measured by the sensor near the end of the stave
- Thermal Image
  - Image: average of 200 frames taken at 25 frames/sec
    - Then converted to thermal profile along stave core cooling pipes
    - Stave is never moved, so the frameanal.py always uses the same stave area
  - Stave Profile Average and Standard Deviation is found to compare measurements

Measurements

- All measurements were done with Stave 6L without ever moving the stave
- To get an average value of the measured variables for comparison, the measured variables are found for the 30 seconds before and after the time the image is taken(using the file timestamp) in the log file.
- The mean and standard deviation for each measured variable is found. The combined uncertainty includes the statistical uncertainty(fluctuations during the time) and the systematic uncertainty(precision of the measuring device)
- Slope of each variable is also found over the 30 seconds before and after the image was taken. This gives an approximate value of the rate of change of that measured variable.

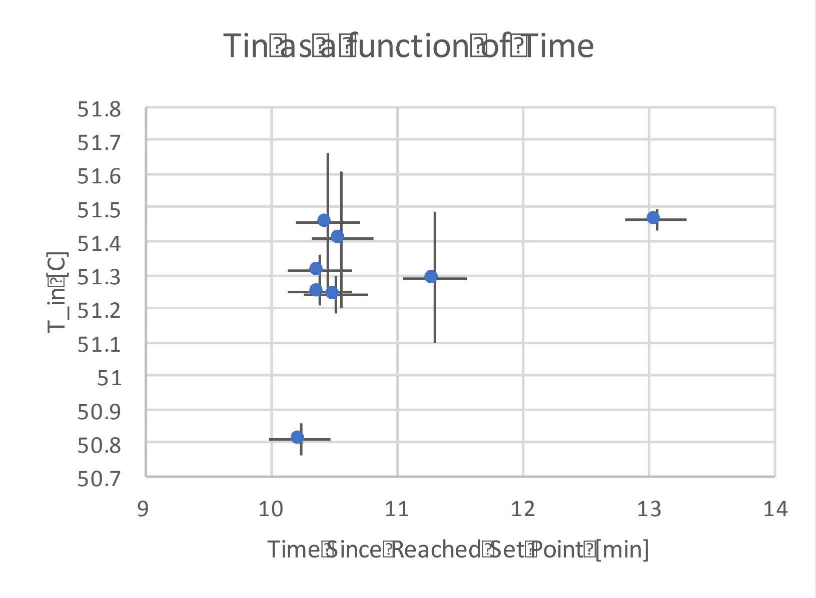
Results: “Identical Measurements” Hot

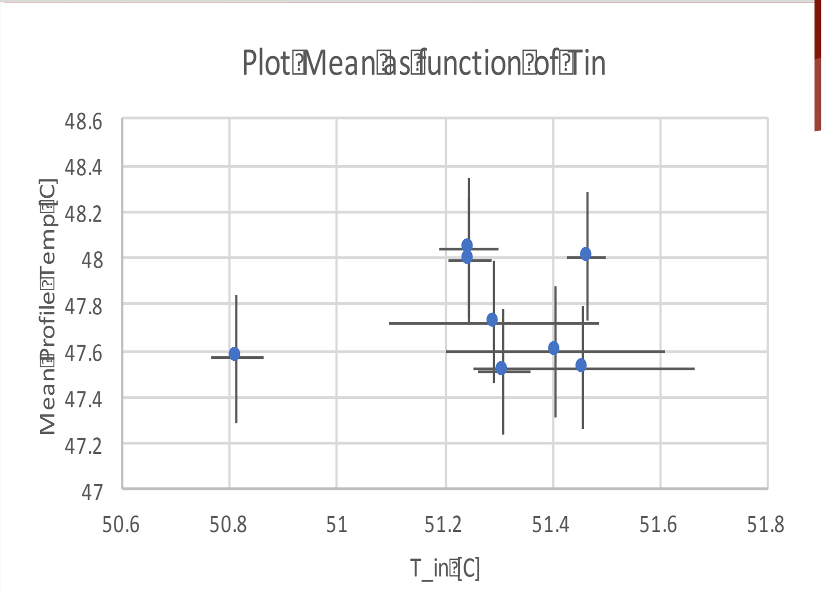
All of these measurements are attempting to do the same measurement.

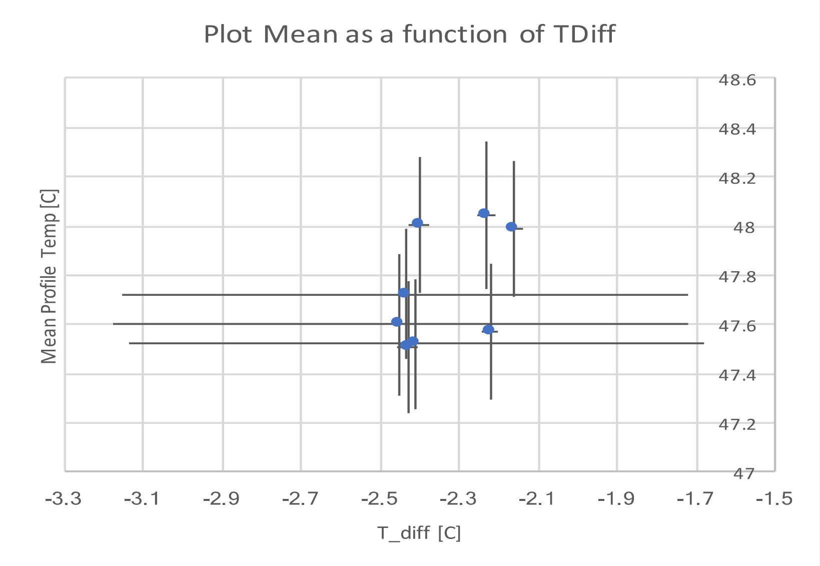
As can be seen, the measurements are not identical within error. Each set has at least one outlier and they are not all the same thermal measurement.

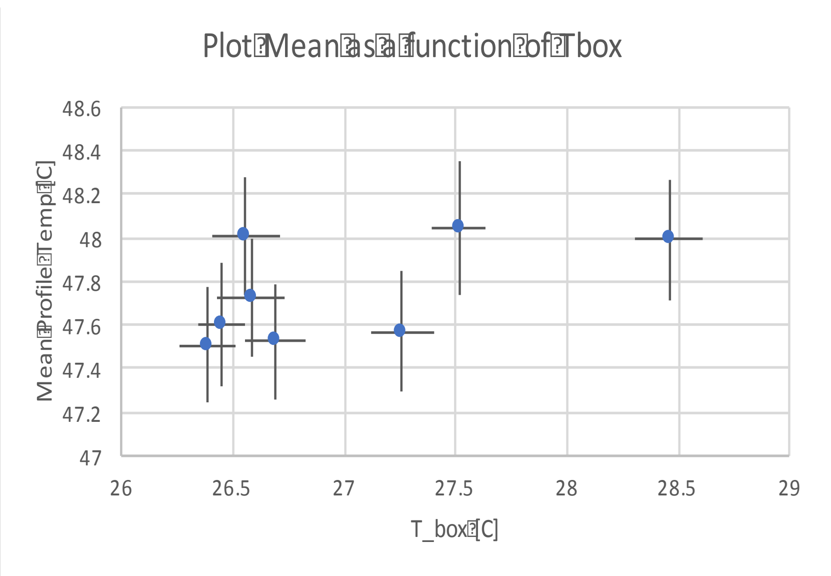
This shows that thermal measurements are difficult to be reproduced at hot temperatures

*The large error bars on some Mean Profile Temps is due to a problem with the thermocouple measurements for 3 trials

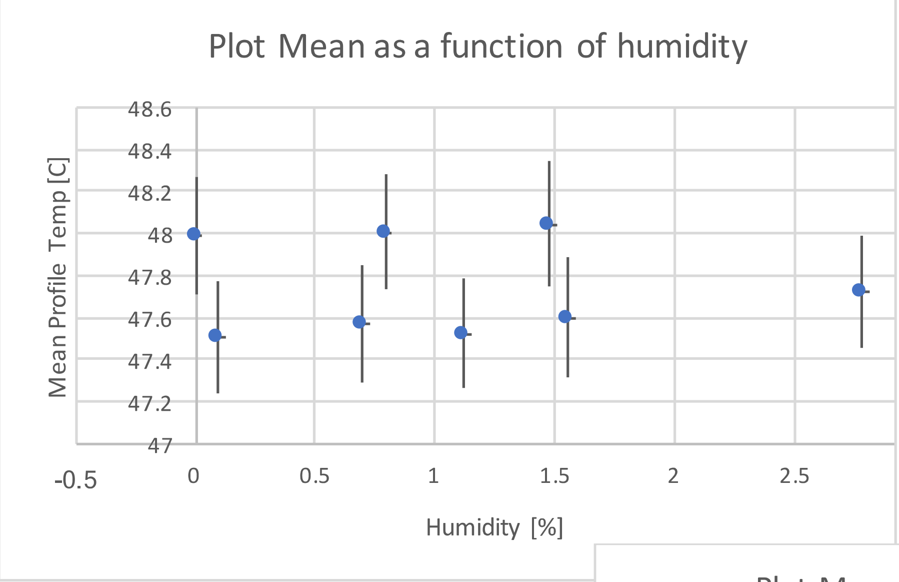


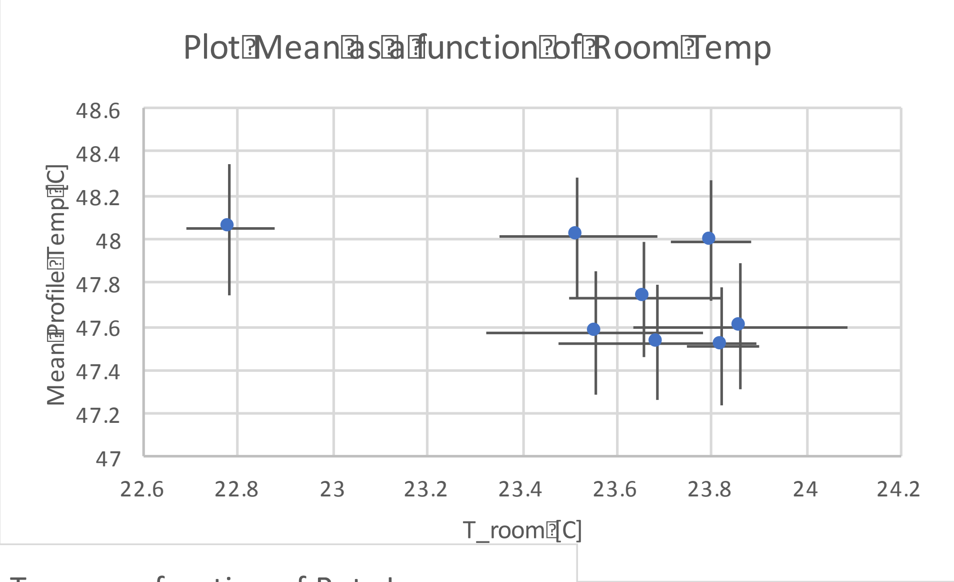


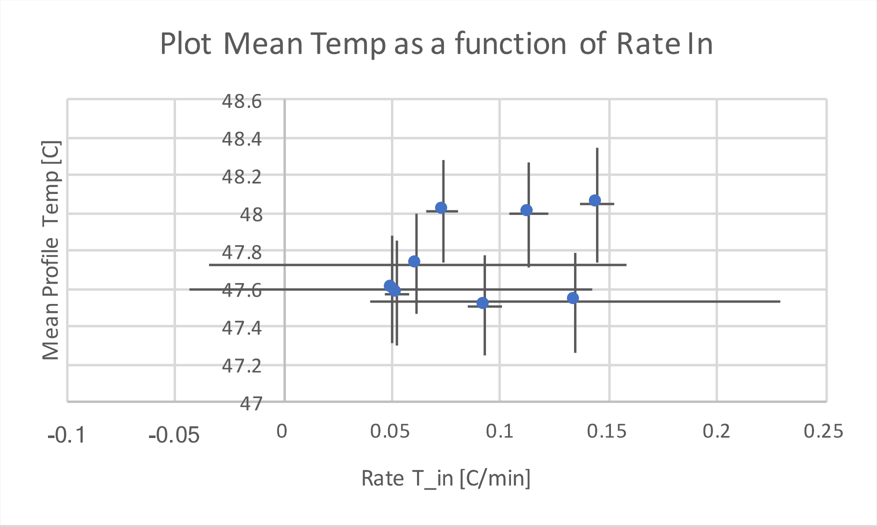




Results: “Identical Measurements” Hot







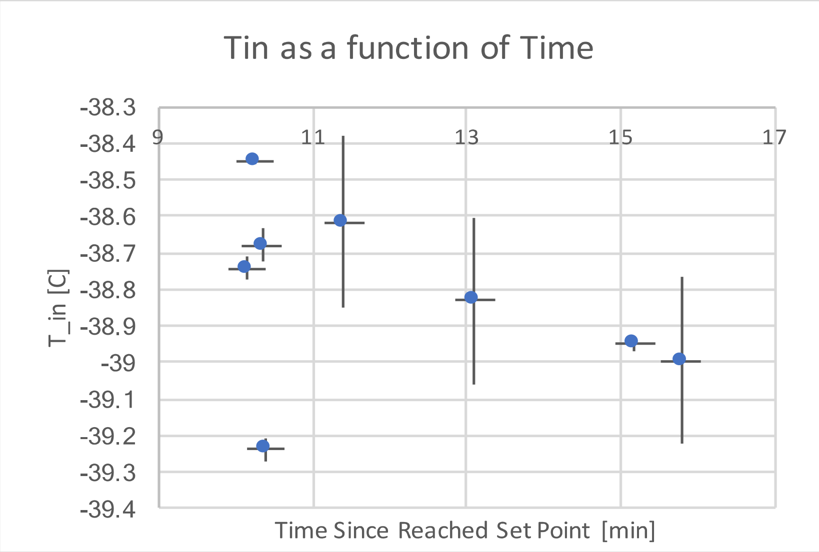
The humidity may have an insignificant effect on the mean profile temp at the low humidity!

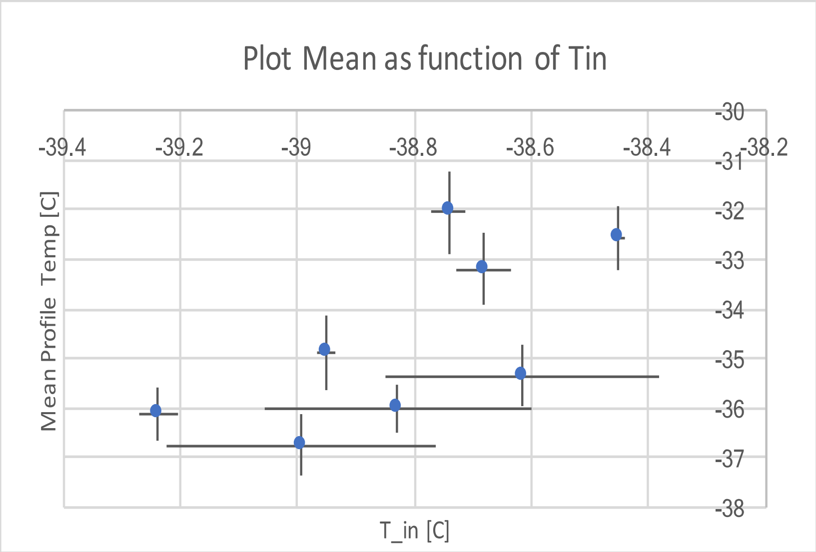
Results: "Identical Measurements" Cold

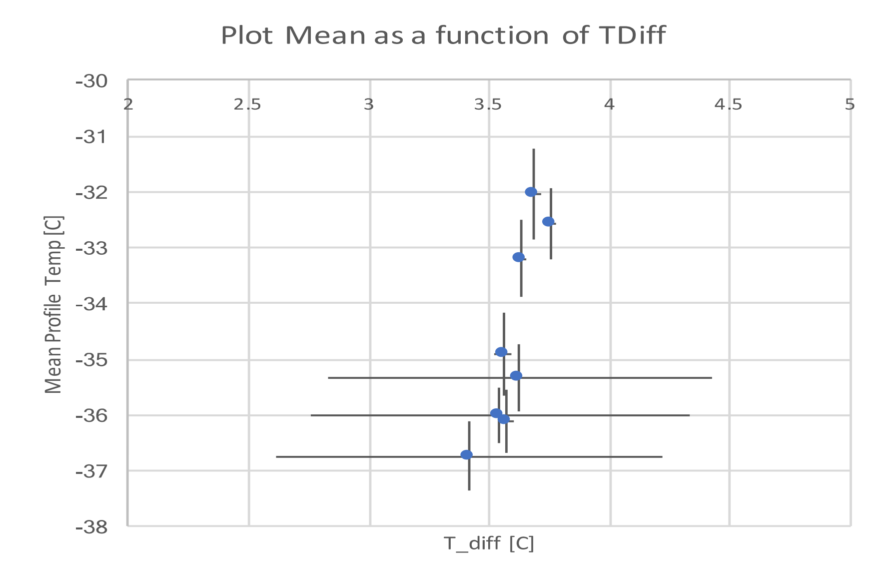
All of these trials are attempting to do the same measurement.

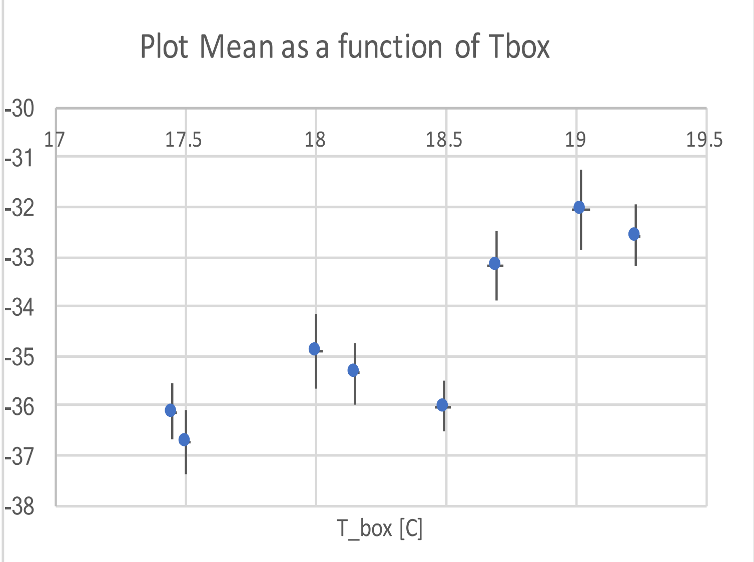
As can be seen, the measurements are not identical within error. These measurements have greater spreads than the hot measurements.

This shows that thermal measurements are even harder to reproduce thermal profiles at cold temperatures!

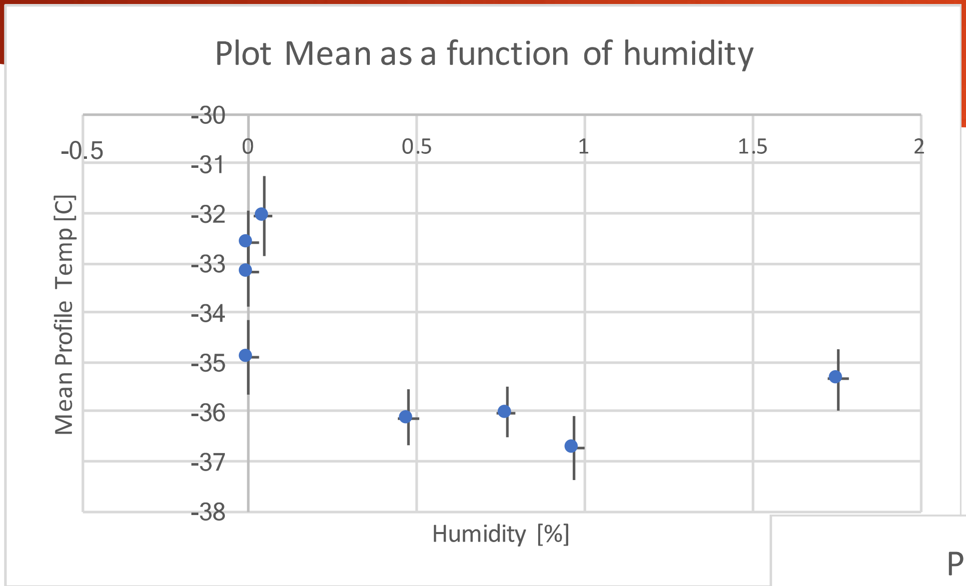


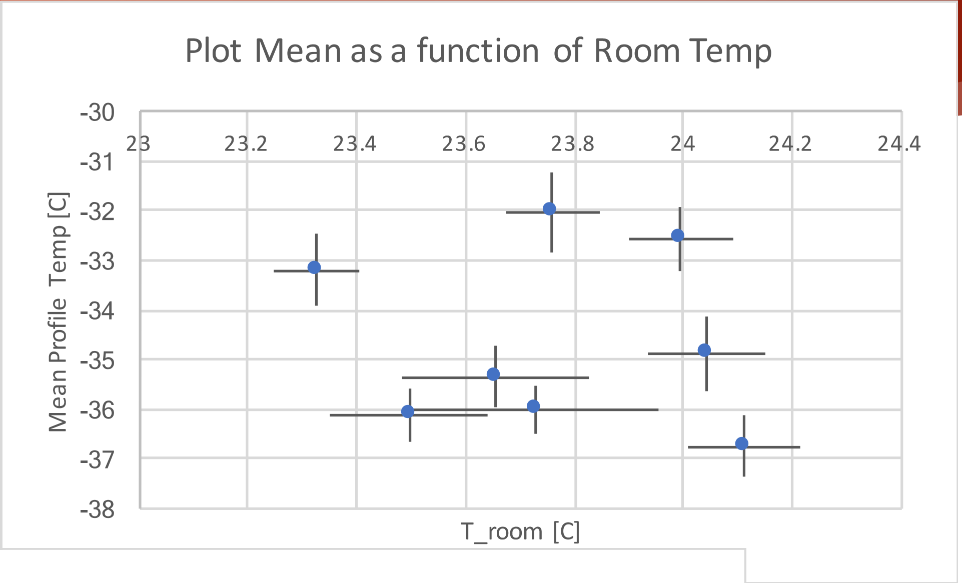


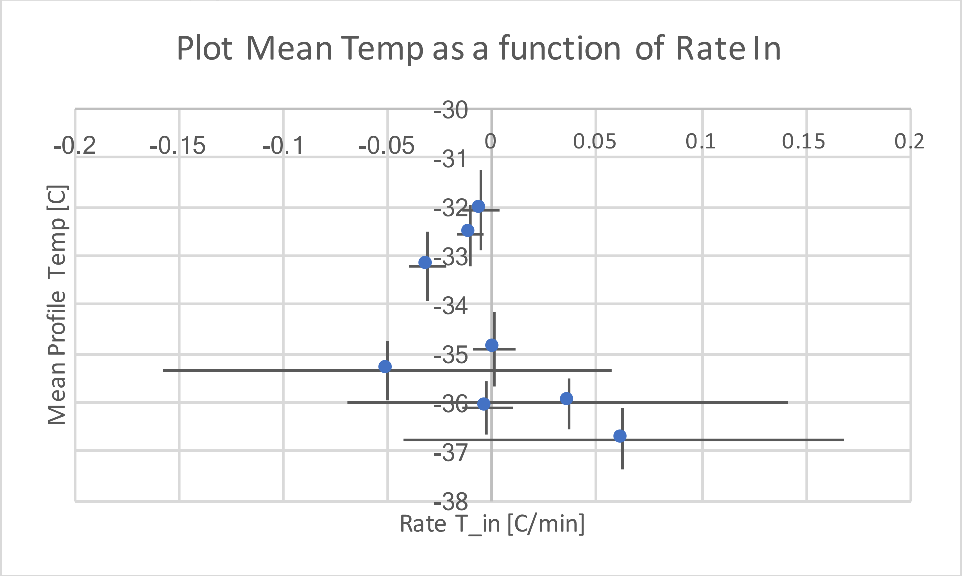




Results: “Identical Measurements” Cold



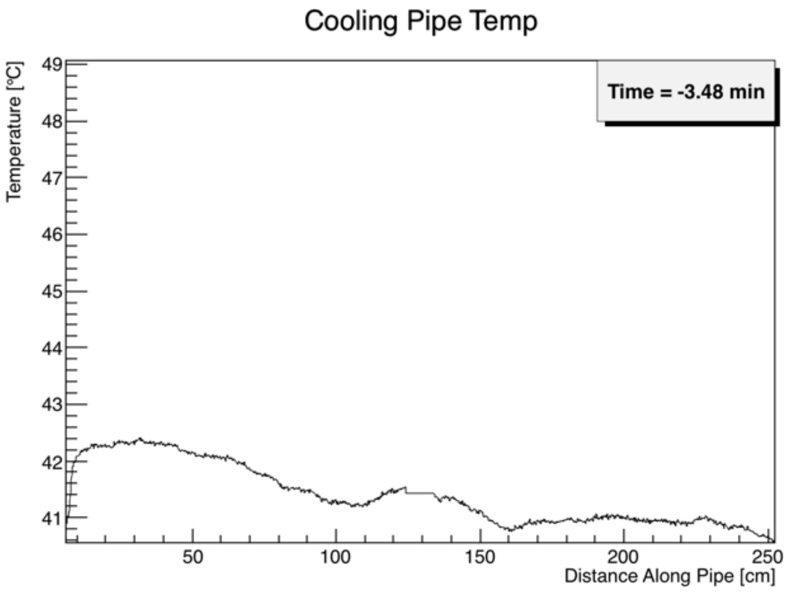


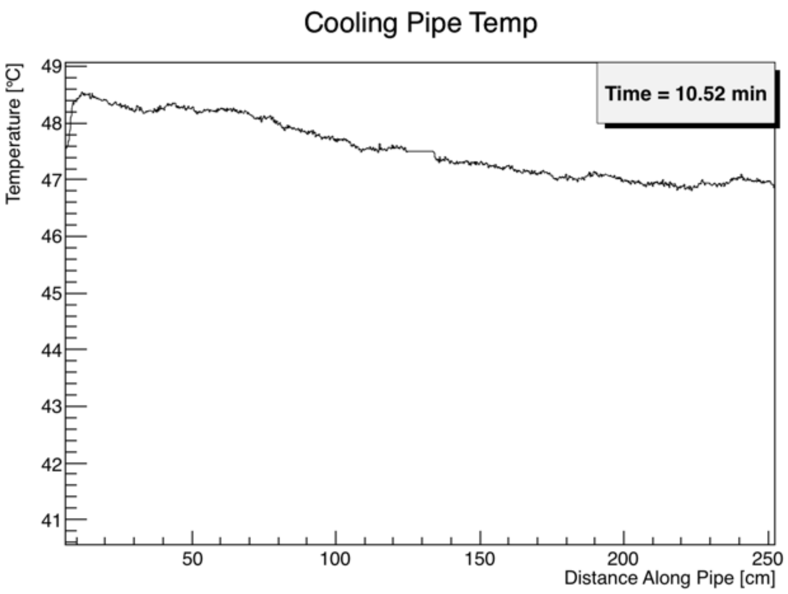


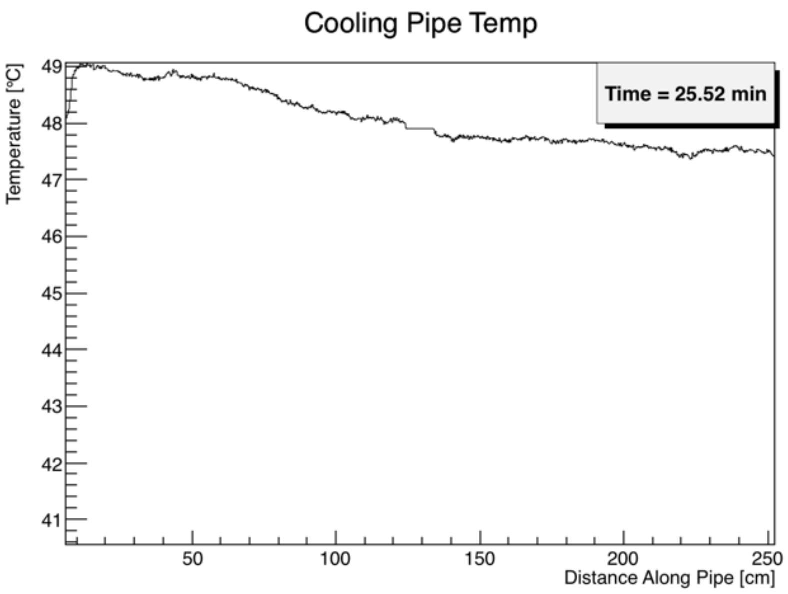
Summary: "Identical Measurements"

- With all of the trials, no two measurements were made with truly identical results within error. Too many different factors effect the thermal profile of the stave. This means that to compare a stave thermal profile measurement from one trial to another they may have different offsets based upon the many different factors.
- Finding the thermal impedance of each stave should show identical results even with different measurement conditions, since it is an intrinsic property of the stave.

Results: Hot T Profile







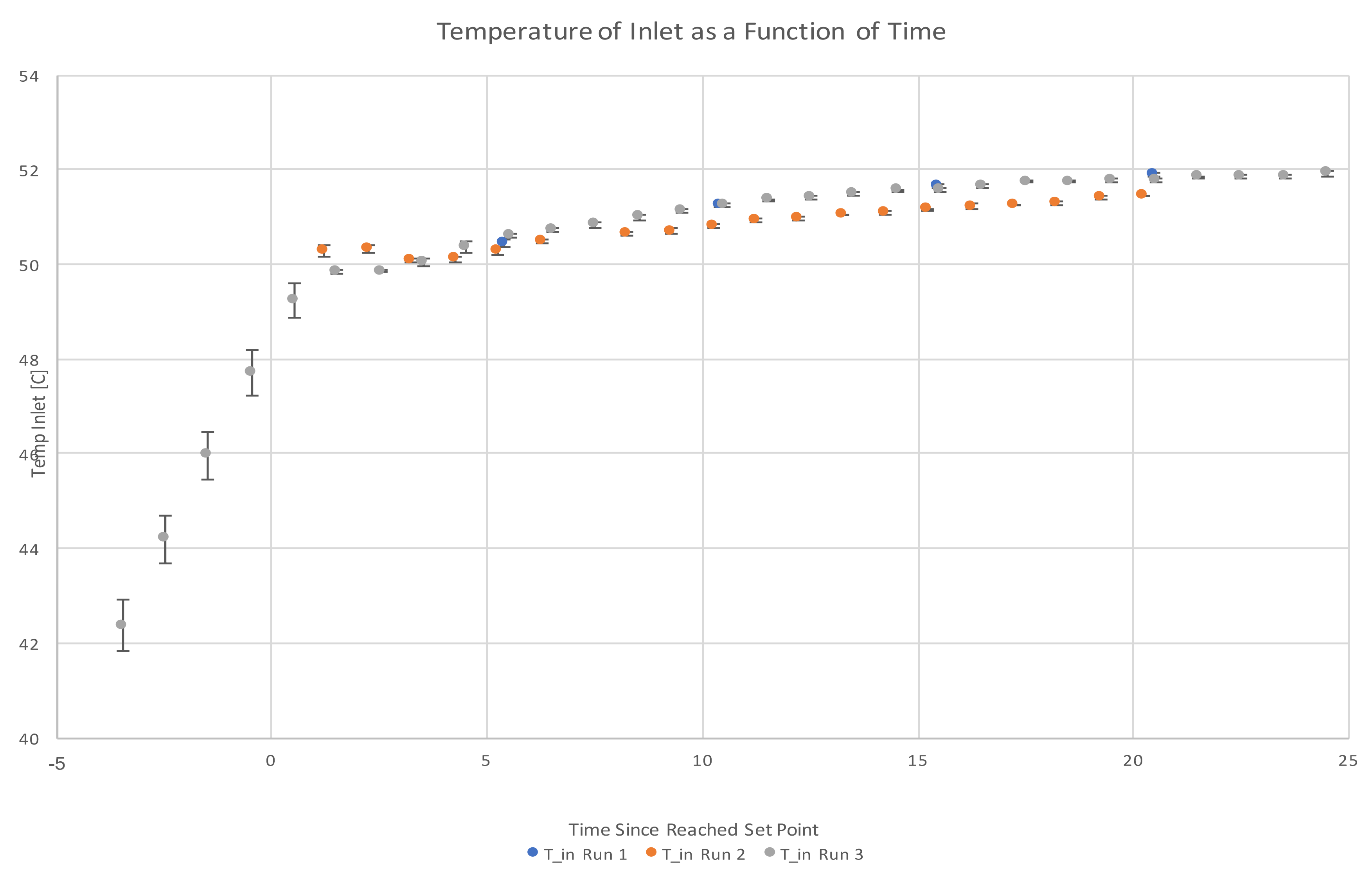
- Thermal profile at different times during Trial 3. When T = 0 min, the N2 is turned off.
- Very small differences between T = 10 and T = 25

Results: T_in Hot

The chiller program has a hook that at around 45.9 C average between inlet and outlet the stave core is said to have reached the set point. This is taken as T = 0. At this time the air is shut off.

For the inlet temperature, it can be seen that the rate of T_in flattens after the N2 is shut off. With the N2 off, there is no longer convection helping to heat the stave.

In all 3 measurements the curves are similar… but not identical within error

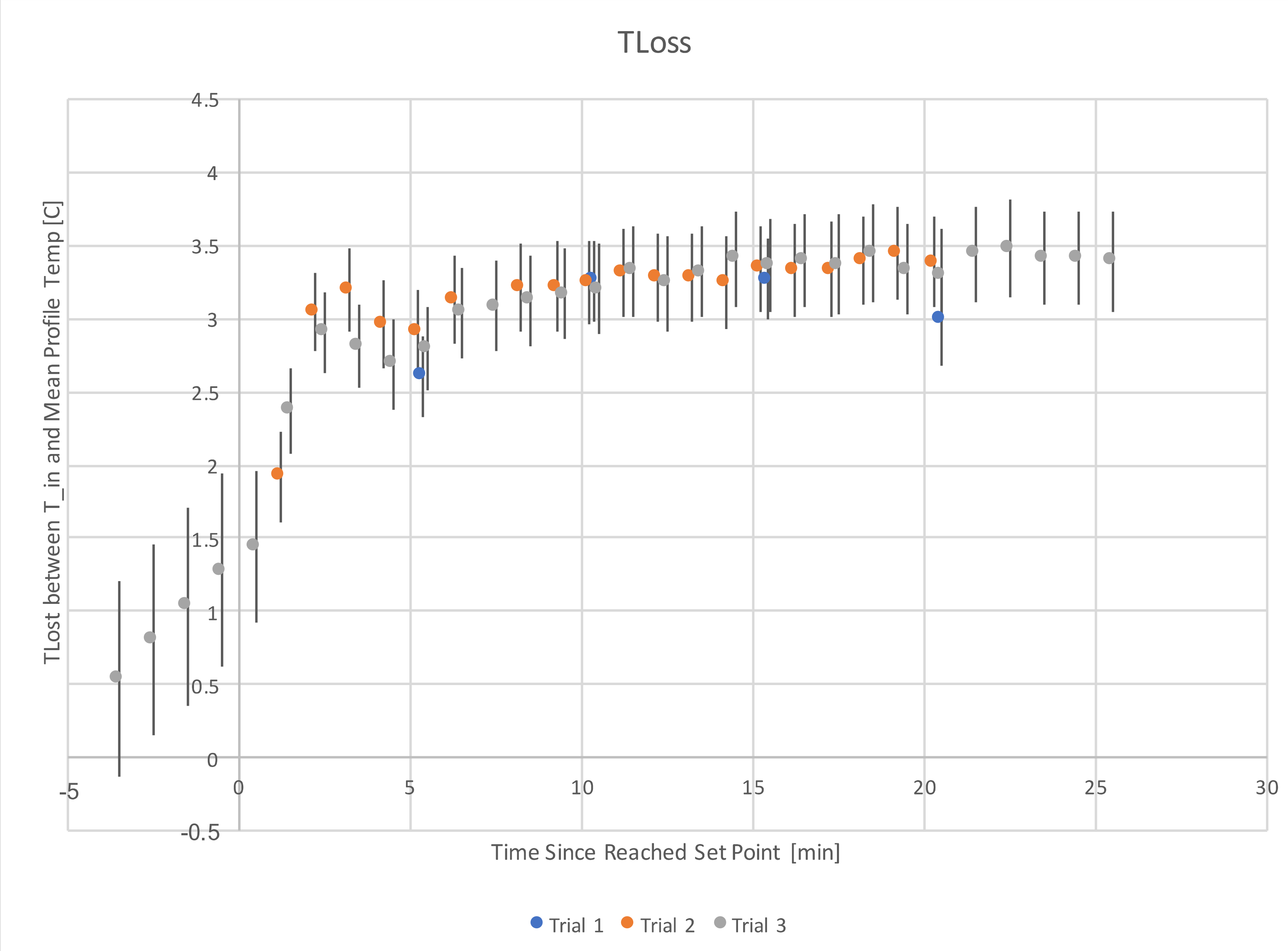


Results: T_Loss Hot

T_Loss is the difference between T_in and the Mean Temperature along the profile of the stave.

As time progresses the T_loss value becomes constant around 3.5 C as a steady state is held between the fluid and stave

All three measurements are identical within error.



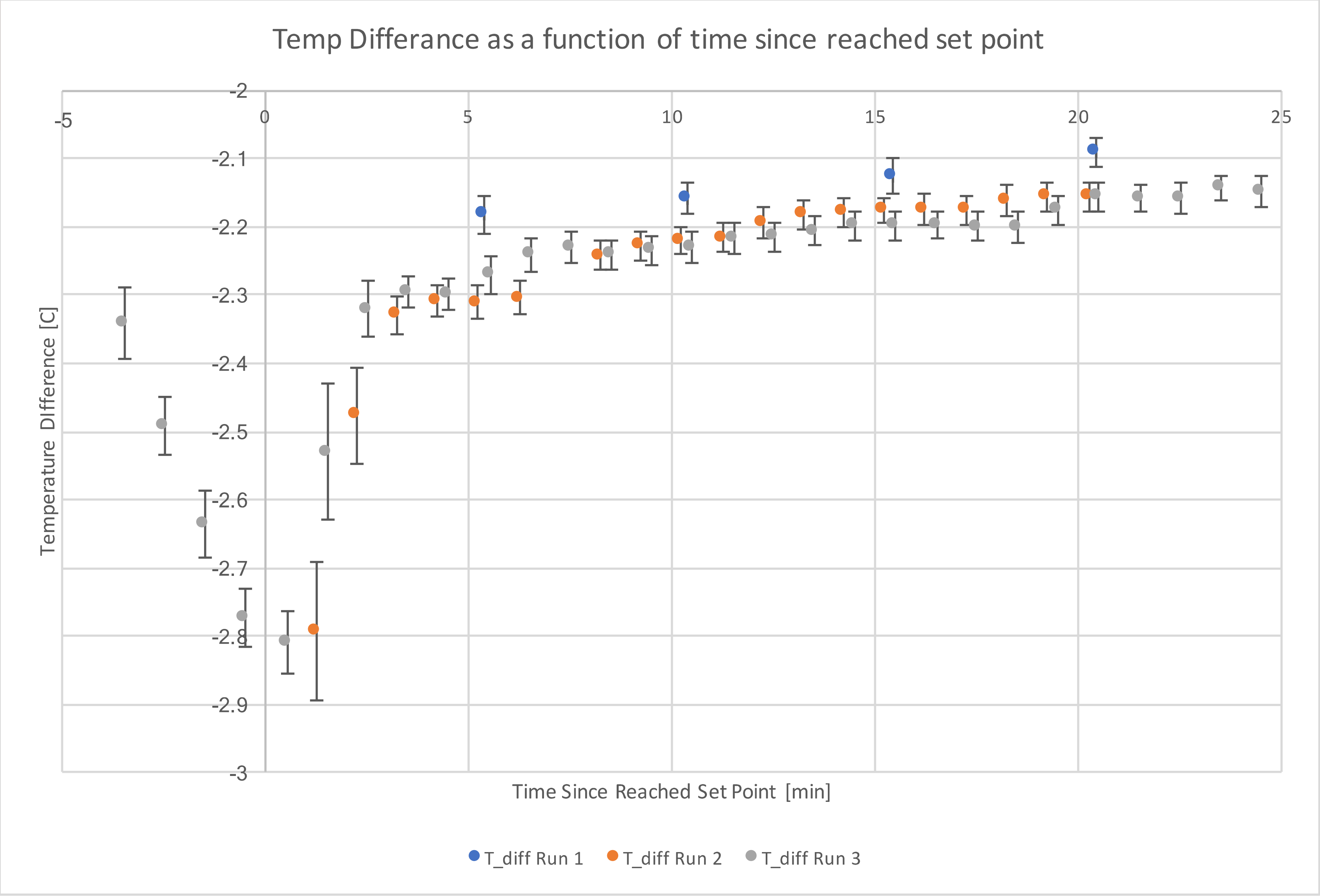
Results: T_diff Hot

T_diff is the difference in temperature between the inlet and outlet of the stave.

With the N2 on T_diff is getting larger at a constant rate while the inlet temperature is going down. If the air was not shut off it would eventually level off into a steady value.

Once the N2 is turned off, the steady state equilibrium is smaller.

The blue measurements are different, but this is due to different box conditions.

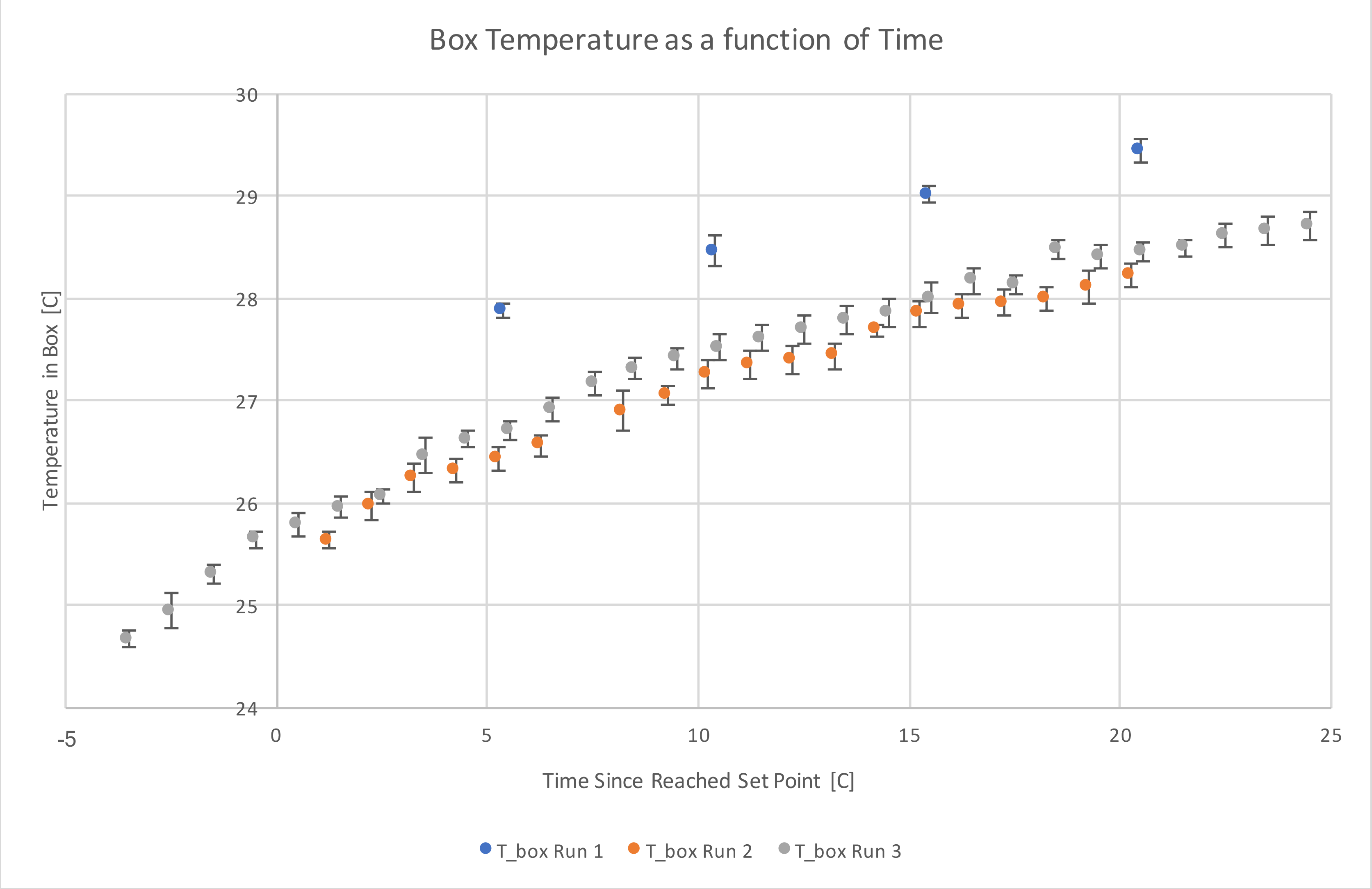


Results: T_box Hot

The box temperature goes up while the stave is above ambient.

The blue data is about 1 C higher. This could be due to length of time heating. The blue curve was taking the system from -40C to +50C, while the other two curves are going from ambient.

The heating curve does not seem to significantly depend on whether the air is blowing or not. Though this could be due to a lack of data

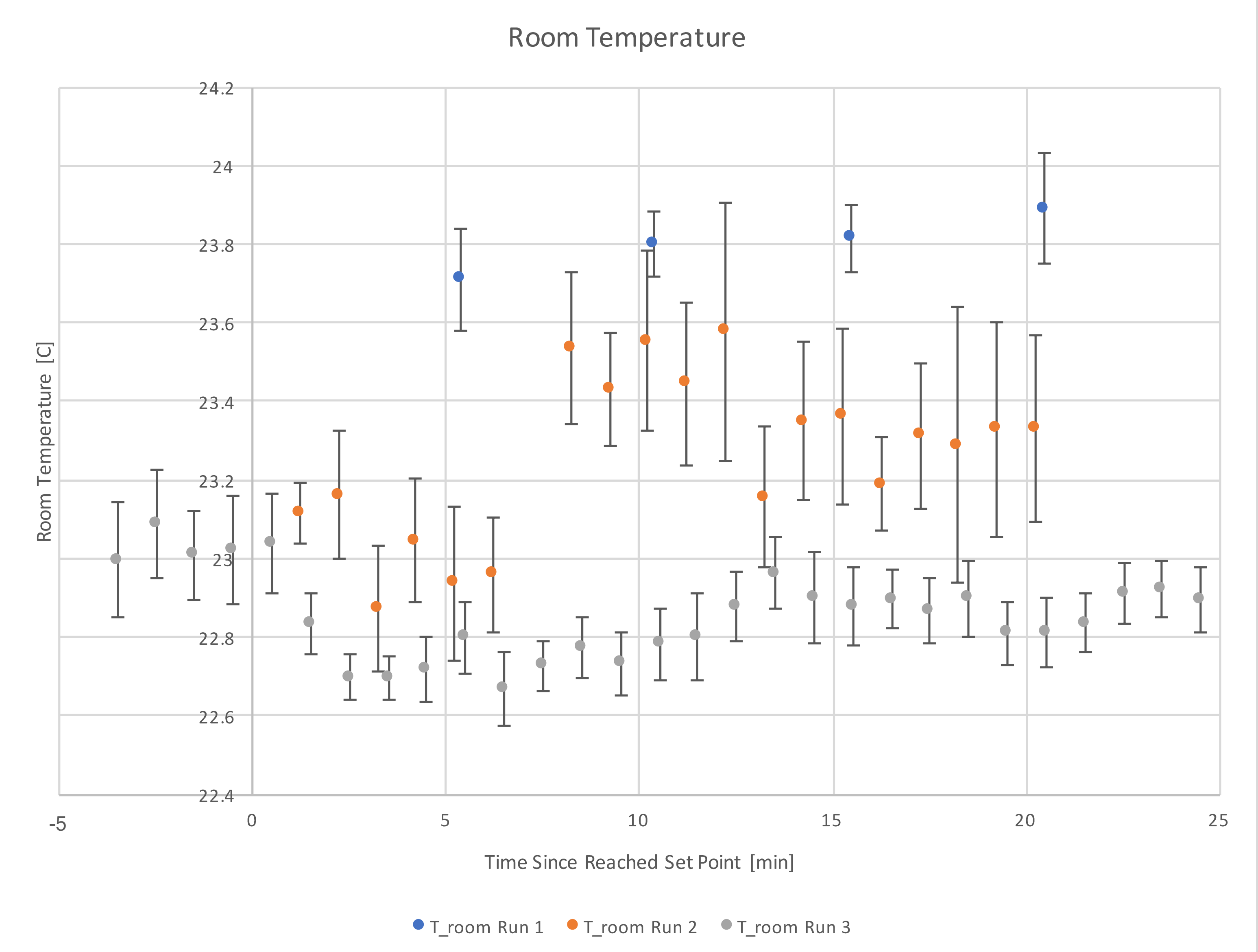


Results: T_room Hot

This is the temperature in the room. It is roughly constant during each run.

The fluctuations are due to the moving air in the room from the air conditioning, chiller, doors opening and closing.

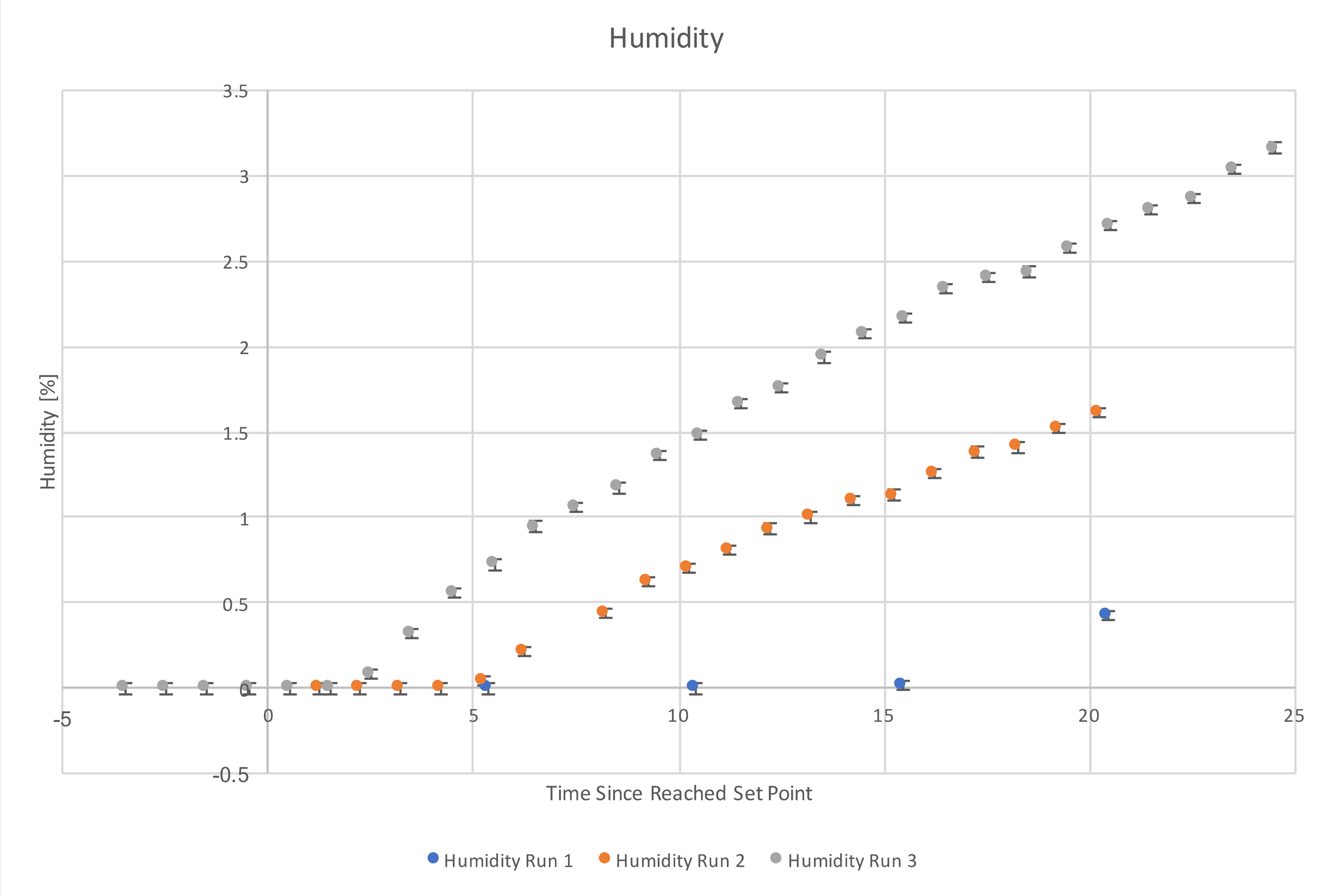
Basically the AC and chiller are competing while the system is running.



Results: Humidity Hot

The humidity in the box goes up at a similar rate in each measurement.

Humidity being high enough to measure depends on how long the box has been purging and the humidity in the room during the measurements.

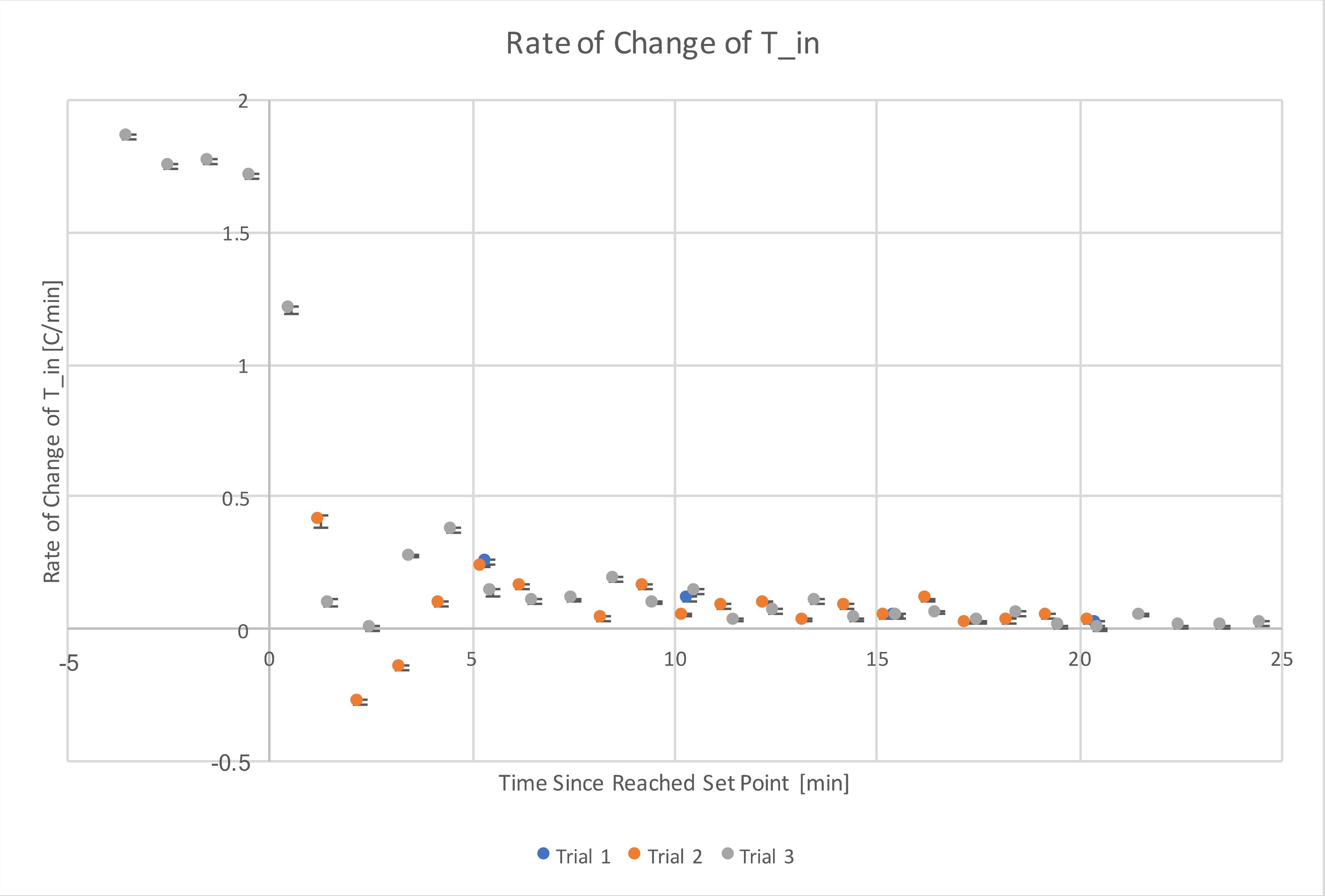


Results: Rate of Change of T_in Hot

This plot is looking at the Rate of change of T_in 30 seconds before and after image is taken.

Before the N2 is shut off RT_in is much higher than after it is shut off. Either way the value should go to 0 as wait time goes to infinity with fluctuations due to the chiller.

All three curves show similar behaviors.

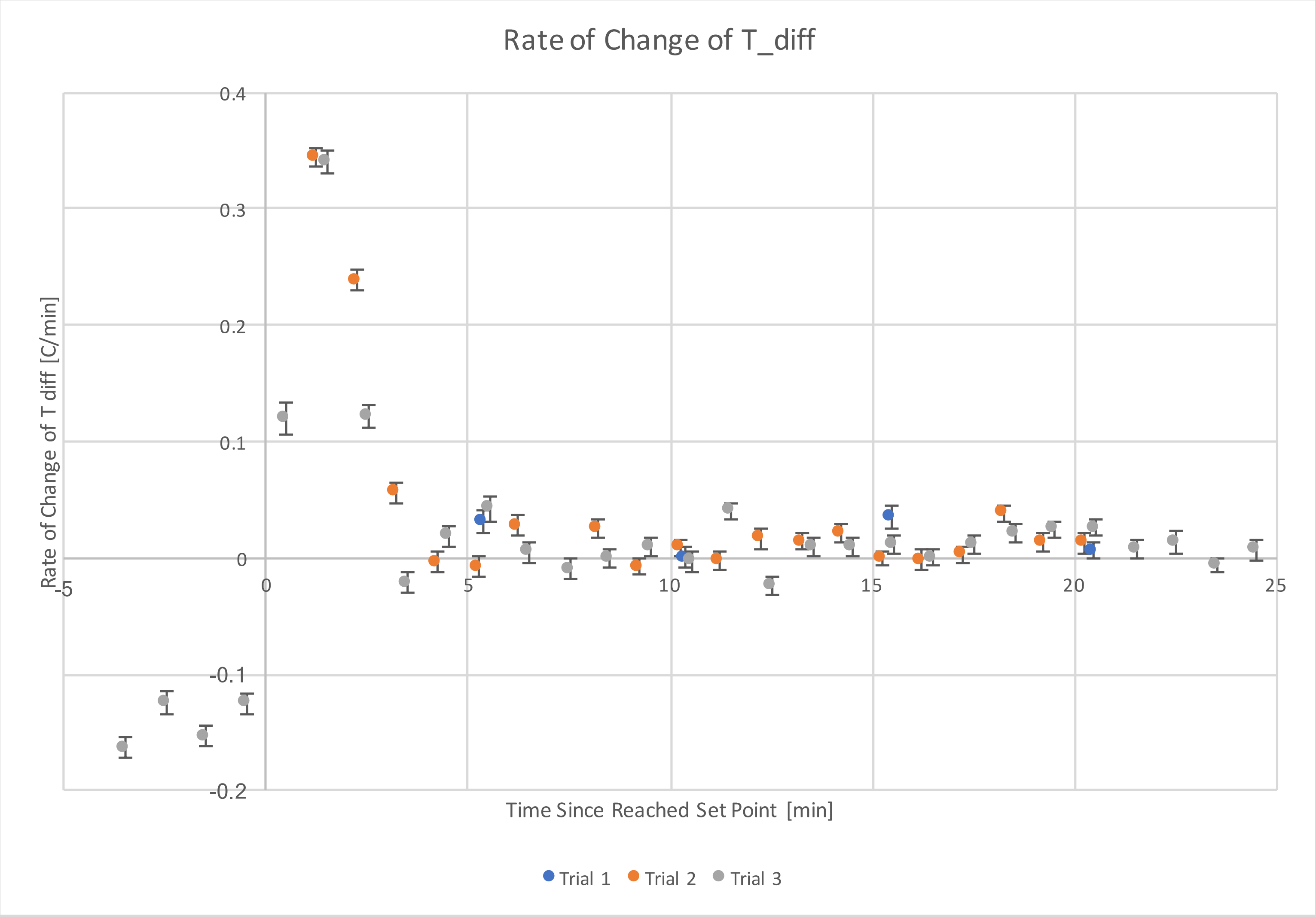


Results: Rate of Change of T_diff Hot

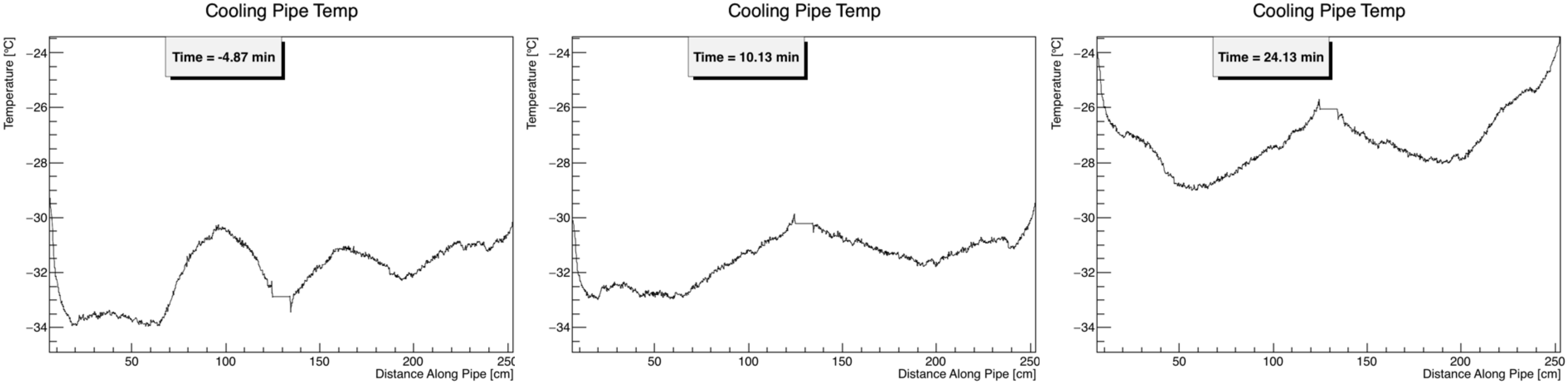
The Rate of change of T_diff is shows the slope over 30 seconds before and after the image is taken.

This shows that before shutting off the air the inlet and outlet are not inlet or outlet until around 5-10 min after shutting off the air.

All three curves are similar



Results: Cold T Profile



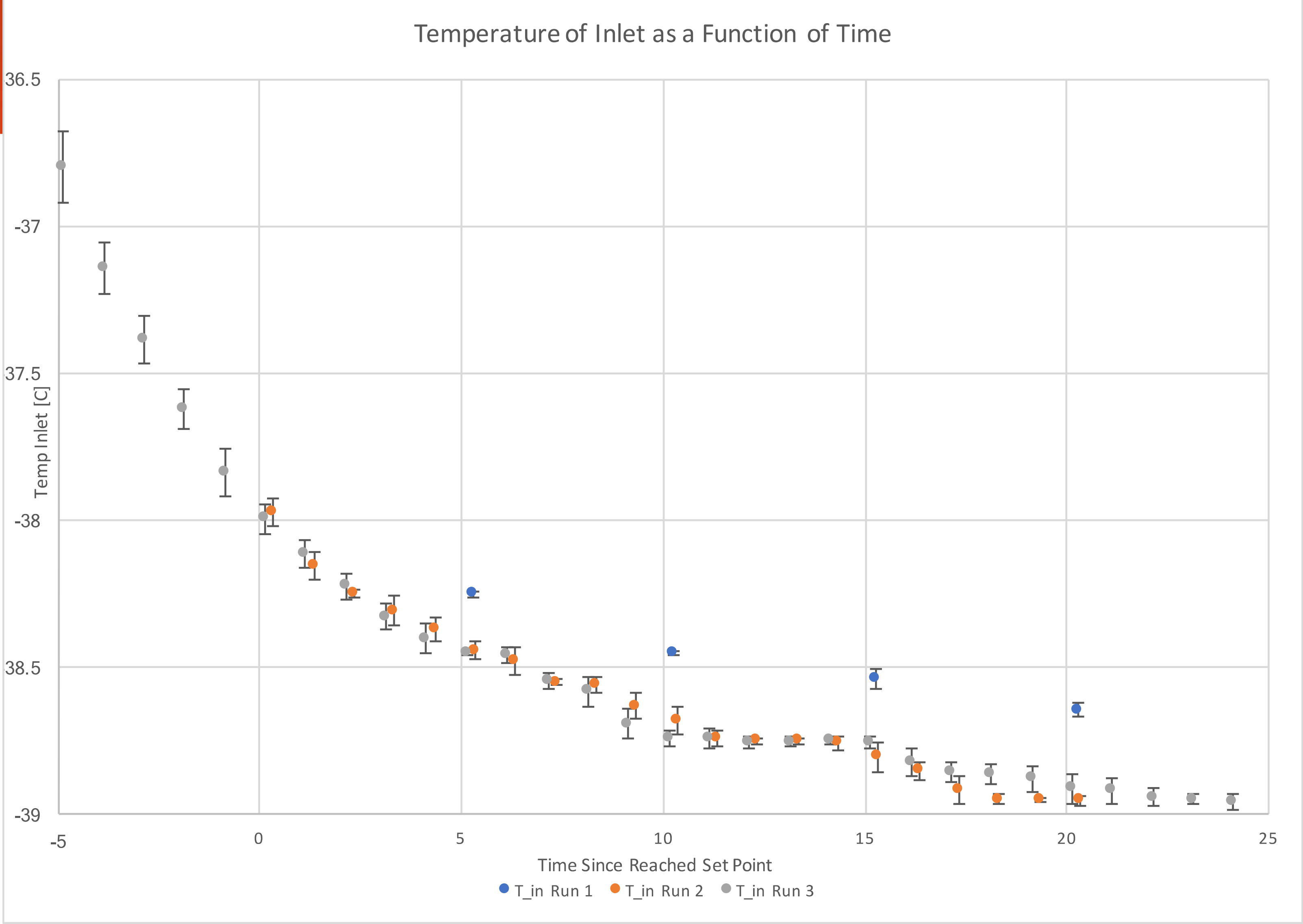
- These three plots show the thermal profile at three different times during Trial 3. At T= 0 the N2 flow is shut off.
- The bumps in the first plot are due to the N2.
- The stave warms at the ends from T = 10 min to T =24 min

Results: T_in Cold

The chiller program has a hook that at around -35 C average between inlet and outlet the stave core is said to have reached the set point. This is taken as T = 0. At this time the air is shut off.

Turning of the air does not seem to have any effect on the inlet temperature.

In all 3 measurements the curves are similar… but not identical. The blue data is higher, but that is due to the box being at a higher temperature, because it was on a 3rd cycle and the box was warmer.



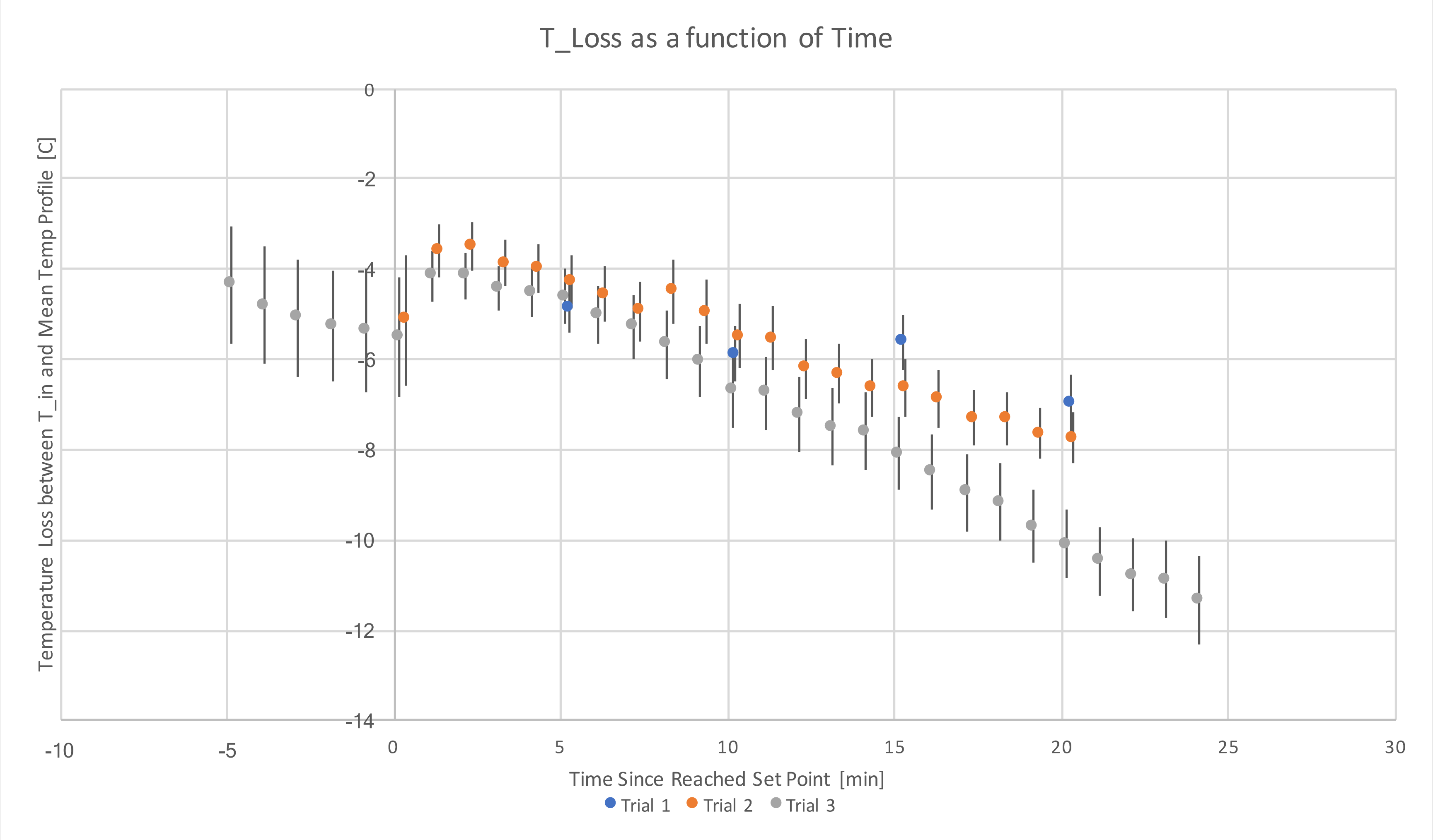
Results: T_Loss Cold

T_Loss is the difference between T_in and the Mean Temperature along the profile of the stave.

As time progresses the T_loss value becomes constant while the air is on.

Once the air is off the stave begins to heat up. This is shown in all three sets of data.

The lack of convection causes the thermal profile to be hotter at the ends of the stave making a W-shape that the hot temperature profile does not show.



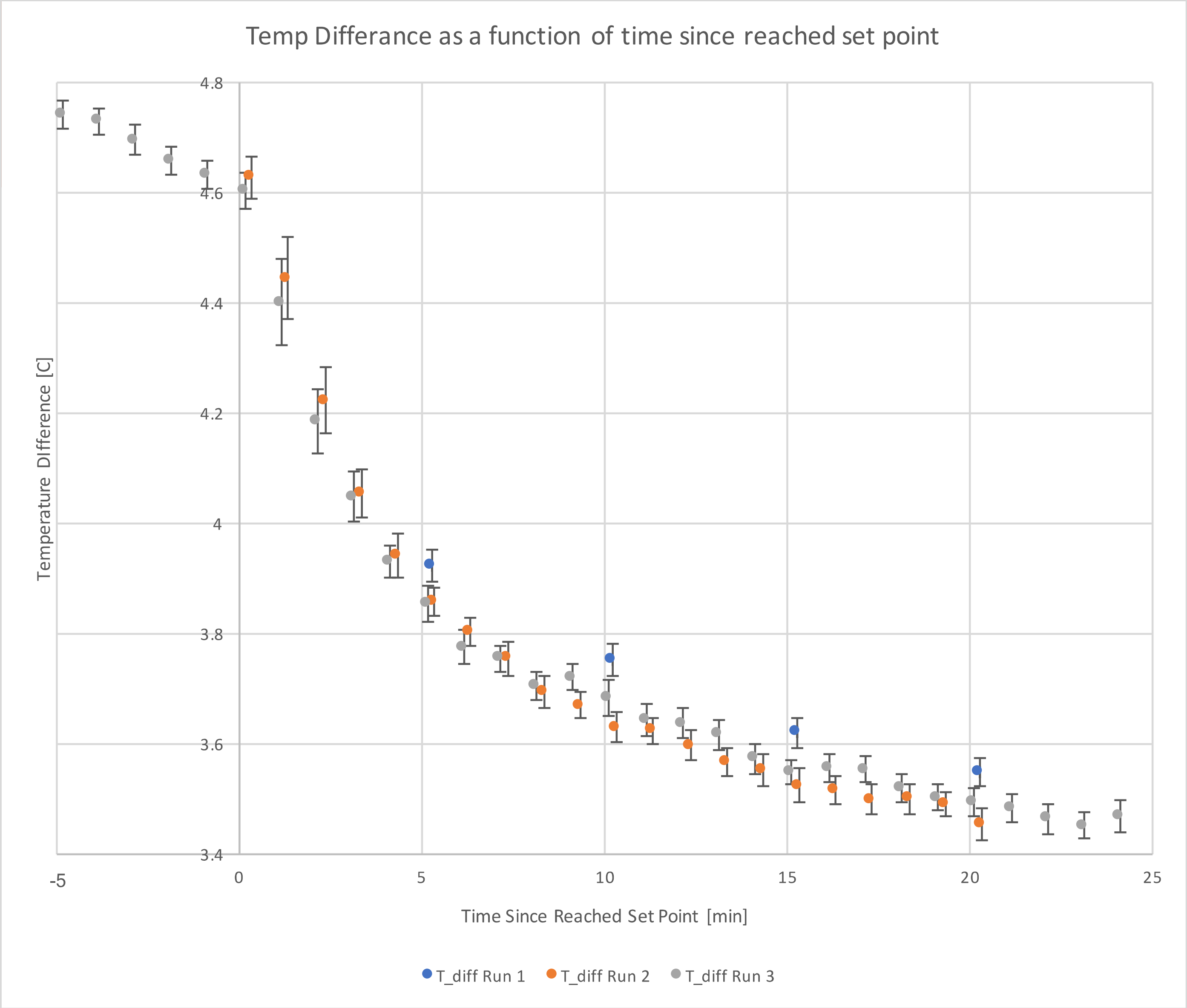
Results: T_diff Cold

T_diff is the difference in temperature between the inlet and outlet of the stave.

With the N2 on, T_diff is getting smaller at a slow rate while the inlet temperature is slowly going down. It is heading toward a constant steady state equillibrium.

Once the N2 is turned off, the steady state equilibrium is smaller.

The blue measurements are different, but this is due to different box conditions.

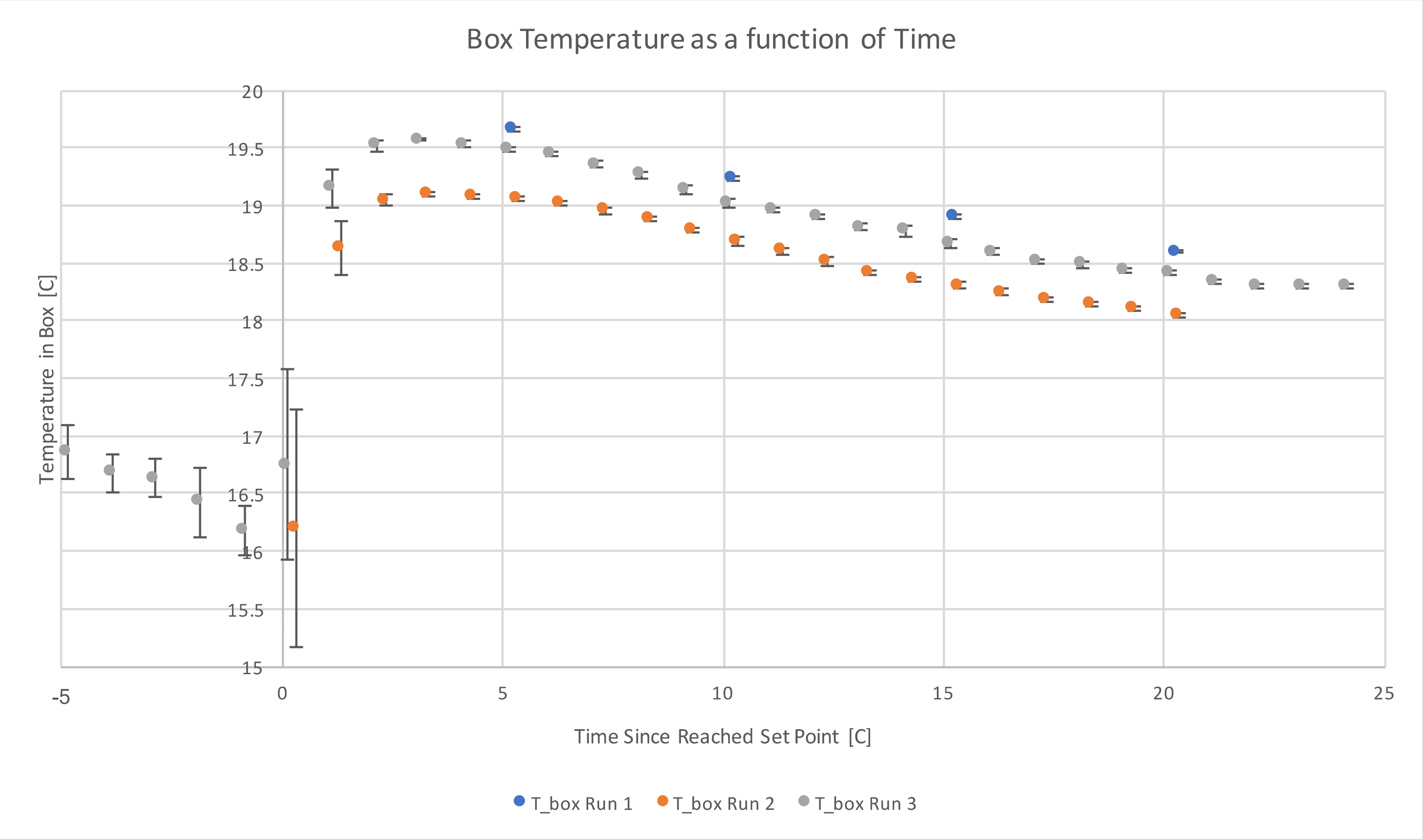


Results: T_box Cold

The box temperature goes down while the stave is below ambient.

Once the air is off, convection due to the air blowing off the stave ceases causing the box to warm up and then it begins to cool to a new steady state.

All three curves seem similar, but are offset, which may be due to slightly different initial conditions, though, the grey and orange runs should be almost identical in all aspects, save slightly different room temperatures.



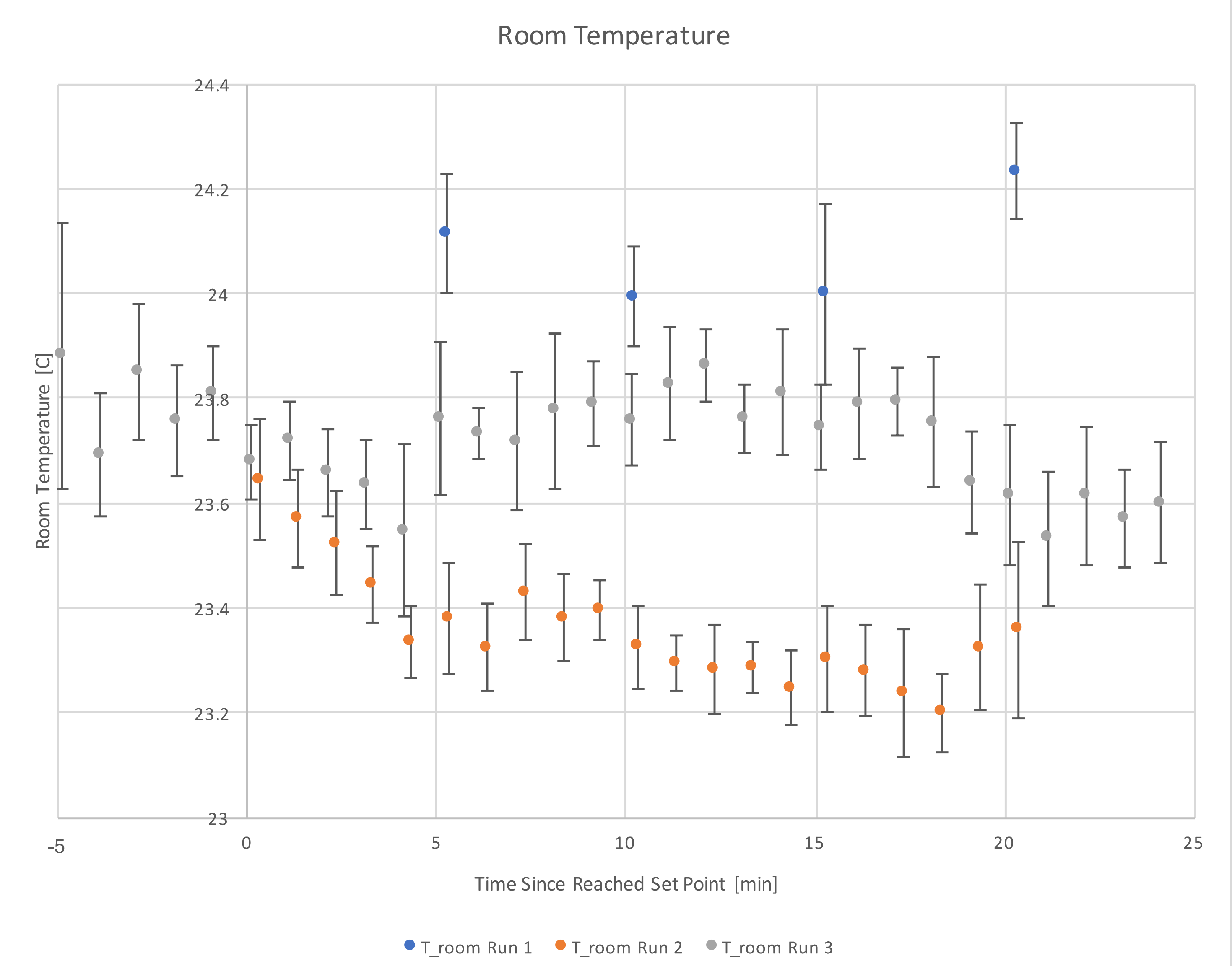
Results: T_room Cold

This is the temperature in the room. It is roughly constant during each run.

The fluctuations are due to the moving air in the room from the air conditioning, chiller, doors opening and closing.

Basically the AC and chiller are competing while the system is running.

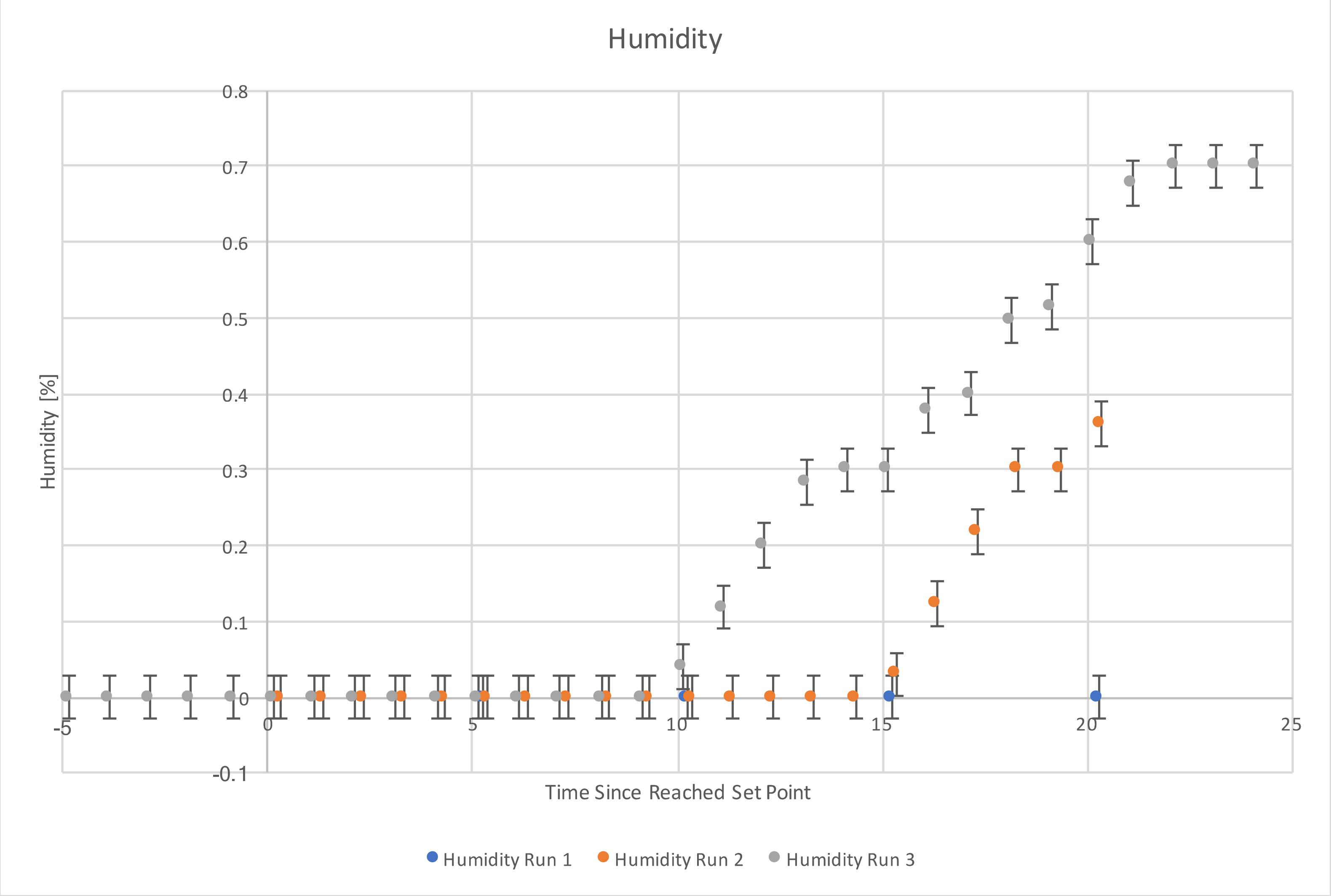
The separation of these curves are similar to the differences in the box temperatures.



Results: Humidity Cold

The humidity in the box goes up at a similar rate in each measurement because the leakiness of the box does not change, but how well it was purged does.

Humidity being high enough to measure depends on how long the box has been purging and the humidity in the room during the measurements.

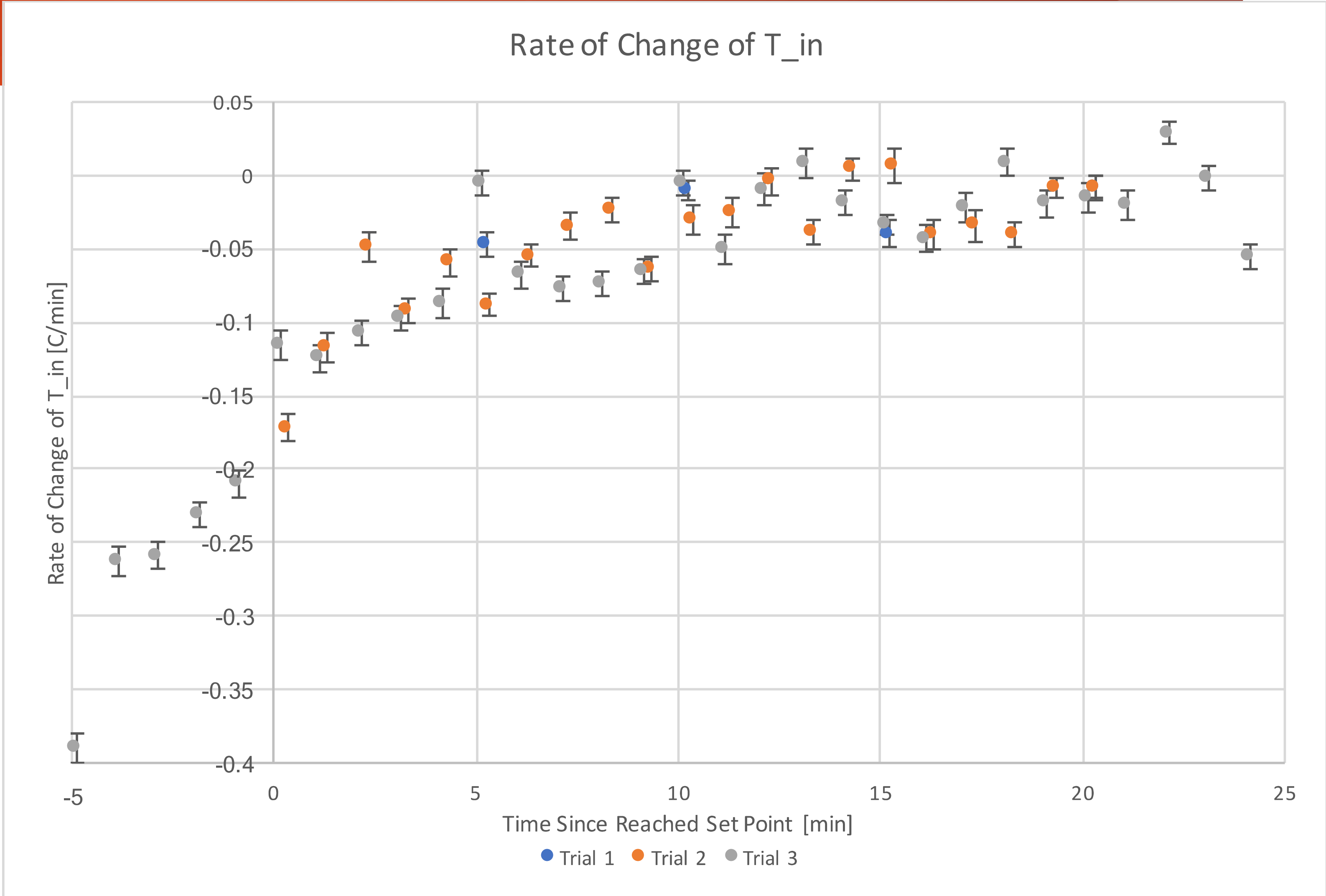


Results: Rate of Change of T_in Cold

This plot is looking at the Rate of change of T_in 30 seconds before and after image is taken.

Shutting off the N2 does not seem to do much with the general trend. The fluid is getting colder and getting closer to 0. It fluctuates due to the chiller trying to keep it at the set temperature.

All three curves show similar behaviors.

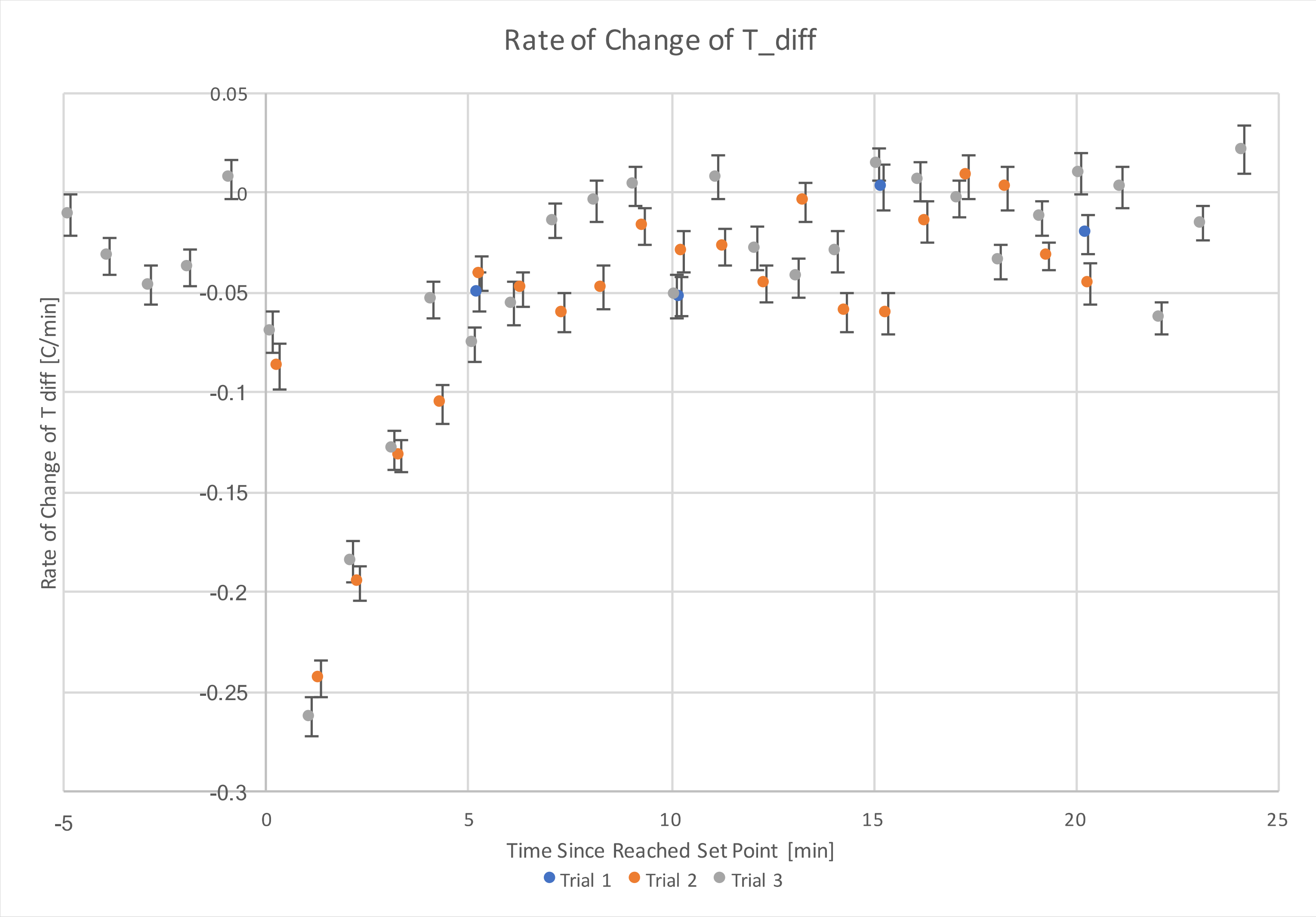


Results: Rate of Change of T_diff Cold

The Rate of change of T_diff is shows the slope over 30 seconds before and after the image is taken.

This shows that before shutting off the air the inlet and outlet are not inlet or outlet until around 5-10 min after shutting off the air.

All three curves are similar



Summary: Hot and Cold

- Fluid Temperature
  - The inlet temperature is heading toward the set temperature in both situations. Turning off the N2 has an effect on the hot fluid by introducing a cusp. It does not seem to have much of an effect on the cold fluid.
  - The absolute difference between the inlet and outlet temperatures goes to an equilibrium state after 5-10 min after turning off the N2.
  - Fluid temperature fluctuates once it reaches equilibrium state due to slight changes in the temperature of the fluid output by the chiller when it is holding at a set temperature
- Stave Mean Temperature Profile
  - The thermal profile changes shape once the effect of N2 is removed. First it loses peaks from the N2, then parts of the stave begin to find a new equilibrium state
    - Cold thermal profiles begin to warm at the ends of the stave
    - Hot thermal profiles see less change but…
  - The absolute difference between the fluid temperature and the thermal profile depends on the cooling mode
    - Cold thermal profiles increase due to the warming of the stave
    - Hot thermal profiles initially increase, but reach an equilibrium state that holds during the rest of the measured time
- Box Conditions
  - The temperature of the box is always heated(cooled) by the stave.
  - Shutting off the N2, causes the box to warm when the system is cold, but seems to have little effect on the warm box temperature.
  - The box temperature is related to the room temperature.
- Though all three trials seem similar, they are not identical within error. This shows that it is very difficult to reproduce identical thermal profiles.

Conclusions

- The thermal profile of a stave core cannot be easily reproduced within error due to large numbers of variables that effect the measurement including:
  - Room conditions: Room temperature and humidity are not directly controllable and they have direct effects on the box temperature
  - Box conditions: Humidity in the box will always increase, when the system is not purging. The box’s temperature is dependent on previous cooling/heating trials and the temperature in the room. Convection caused by the N2 flow effects the cooling/heating of the box.
  - Chilling conditions: The chiller always tries to get to its set temperature, and will add in fluctuations once it reaches its set value.
- Future: Thermal impedance measurements!