


```

In [1]: import itclab
import numpy as np
import time
import matplotlib.pyplot as plt
from scipy.integrate import odeint

#####
# Use this script for evaluating model predictions #
# and PID controller performance for the TCLab #
# Adjust only PID and model sections #
#####

#####
# PID Controller #
#####
# inputs -----
# sp = setpoint
# pv = current temperature
# pv_last = prior temperature
# ierr = integral error
# dt = time increment between measurements
# outputs -----
# op = output of the PID controller
# P = proportional contribution
# I = integral contribution
# D = derivative contribution
def pid(sp,pv,pv_last,ierr,dt):
    Kc = 10.0 # K/%Heater
    tauI = 50.0 # sec
    tauD = 1.0 # sec
    # Parameters in terms of PID coefficients
    KP = Kc
    KI = Kc/tauI
    KD = Kc*tauD
    # ubias for controller (initial heater)
    op0 = 0
    # upper and lower bounds on heater Level
    ophi = 100
    oplo = 0
    # calculate the error
    error = sp-pv
    # calculate the integral error
    ierr = ierr + KI * error * dt
    # calculate the measurement derivative
    dpv = (pv - pv_last) / dt
    # calculate the PID output
    P = KP * error
    I = ierr
    D = -KD * dpv
    op = op0 + P + I + D
    # implement anti-reset windup
    if op < oplo or op > ophi:
        I = I - KI * error * dt
        # clip output
        op = max(oplo,min(ophi,op))
    # return the controller output and PID terms

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    return [op,P,I,D]

#####
# FOPDT model
#####
Kp = 0.5      # degC/%
tauP = 120.0  # seconds
thetaP = 10   # seconds (integer)
Tss = 23     # degC (ambient temperature)
Qss = 0      # % heater

#####
# Energy balance model
#####
def heat(x,t,Q):
    # Parameters
    Ta = 23 + 273.15 # K
    U = 10.0         # W/m^2-K
    m = 4.0/1000.0   # kg
    Cp = 0.5 * 1000.0 # J/kg-K
    A = 12.0 / 100.0**2 # Area in m^2
    alpha = 0.01     # W / % heater
    eps = 0.9        # Emissivity
    sigma = 5.67e-8  # Stefan-Boltzman

    # Temperature State
    T = x[0]

    # Nonlinear Energy Balance
    dTdt = (1.0/(m*Cp))*(U*A*(Ta-T) \
            + eps * sigma * A * (Ta**4 - T**4) \
            + alpha*Q)
    return dTdt

#####
# Do not adjust anything below this point
#####

# Connect to Arduino
a = itclab.iTCLab()

# Turn LED on
print('LED On')
a.LED(100)

# Run time in minutes
run_time = 15.0

# Number of cycles
loops = int(60.0*run_time)
tm = np.zeros(loops)

# Temperature
# set point (degC)
Tsp1 = np.ones(loops) * 25.0
Tsp1[60:] = 45.0
Tsp1[360:] = 30.0

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Tsp1[660:] = 35.0
T1 = np.ones(loops) * a.T1 # measured T (degC)
error_sp = np.zeros(loops)

Tsp2 = np.ones(loops) * 23.0 # set point (degC)
T2 = np.ones(loops) * a.T2 # measured T (degC)

# Predictions
Tp = np.ones(loops) * a.T1
error_eb = np.zeros(loops)
Tp1 = np.ones(loops) * a.T1
error_fopdt = np.zeros(loops)

# impulse tests (0 - 100%)
Q1 = np.ones(loops) * 0.0
Q2 = np.ones(loops) * 0.0

print('Running Main Loop. Ctrl-C to end.')
print(' Time      SP      PV      Q1 = P + I + D')
print('{:6.1f} {:6.2f} {:6.2f} ' + \
      '{:6.2f} {:6.2f} {:6.2f} {:6.2f}').format( \
      tm[0],Tsp1[0],T1[0], \
      Q1[0],0.0,0.0,0.0))

# Create plot
plt.figure(figsize=(10,7))
plt.ion()
plt.show()

# Main Loop
start_time = time.time()
prev_time = start_time
# Integral error
ierr = 0.0
try:
    for i in range(1,loops):
        # Sleep time
        sleep_max = 1.0
        sleep = sleep_max - (time.time() - prev_time)
        if sleep>=0.01:
            time.sleep(sleep-0.01)
        else:
            time.sleep(0.01)

        # Record time and change in time
        t = time.time()
        dt = t - prev_time
        prev_time = t
        tm[i] = t - start_time

        # Read temperatures in Kelvin
        T1[i] = a.T1
        T2[i] = a.T2

        # Simulate one time step with Energy Balance
        Tnext = odeint(heat,Tp[i-1]+273.15,[0,dt],args=(Q1[i-1],))
        Tp[i] = Tnext[1]-273.15

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# Simulate one time step with Linear FOPDT model
z = np.exp(-dt/tauP)
Tpl[i] = (Tpl[i-1]-Tss) * z \
        + (Q1[max(0,i-int(thetaP)-1)]-Qss)*(1-z)*Kp \
        + Tss

# Calculate PID output
[Q1[i],P,ierr,D] = pid(Tsp1[i],T1[i],T1[i-1],ierr,dt)

# Start setpoint error accumulation after 1 minute (60 seconds)
if i>=60:
    error_eb[i] = error_eb[i-1] + abs(Tp[i]-T1[i])
    error_fopdt[i] = error_fopdt[i-1] + abs(Tpl[i]-T1[i])
    error_sp[i] = error_sp[i-1] + abs(Tsp1[i]-T1[i])

# Write output (0-100)
a.Q1(Q1[i])
a.Q2(0.0)

# Print line of data
print('{:6.1f} {:6.2f} {:6.2f} ' + \
      '{:6.2f} {:6.2f} {:6.2f} {:6.2f}').format( \
      tm[i],Tsp1[i],T1[i], \
      Q1[i],P,ierr,D)

# Plot
plt.clf()
ax=plt.subplot(4,1,1)
ax.grid()
plt.plot(tm[0:i],T1[0:i],'r.',label=r'$T_1$ measured')
plt.plot(tm[0:i],Tsp1[0:i],'k--',label=r'$T_1$ set point')
plt.ylabel('Temperature (degC)')
plt.legend(loc=2)
ax=plt.subplot(4,1,2)
ax.grid()
plt.plot(tm[0:i],Q1[0:i],'b-',label=r'$Q_1$')
plt.ylabel('Heater')
plt.legend(loc='best')
ax=plt.subplot(4,1,3)
ax.grid()
plt.plot(tm[0:i],T1[0:i],'r.',label=r'$T_1$ measured')
plt.plot(tm[0:i],Tp[0:i],'k-',label=r'$T_1$ energy balance')
plt.plot(tm[0:i],Tpl[0:i],'g-',label=r'$T_1$ linear model')
plt.ylabel('Temperature (degC)')
plt.legend(loc=2)
ax=plt.subplot(4,1,4)
ax.grid()
plt.plot(tm[0:i],error_sp[0:i],'r-',label='Set Point Error')
plt.plot(tm[0:i],error_eb[0:i],'k-',label='Energy Balance Error')
plt.plot(tm[0:i],error_fopdt[0:i],'g-',label='Linear Model Error')
plt.ylabel('Cumulative Error')
plt.legend(loc='best')
plt.xlabel('Time (sec)')
plt.draw()
plt.pause(0.05)

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# Turn off heaters
a.Q1(0)
a.Q2(0)
# Save figure
plt.savefig('test_PID.png')

# Allow user to end loop with Ctrl-C
except KeyboardInterrupt:
    # Disconnect from Arduino
    a.Q1(0)
    a.Q2(0)
    print('Shutting down')
    a.close()
    plt.savefig('test_PID.png')

# Make sure serial connection still closes when there's an error
except:
    # Disconnect from Arduino
    a.Q1(0)
    a.Q2(0)
    print('Error: Shutting down')
    a.close()
    plt.savefig('test_PID.png')
    raise

a.close()

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Opening connection

iTCLab connected via Arduino on port COM3

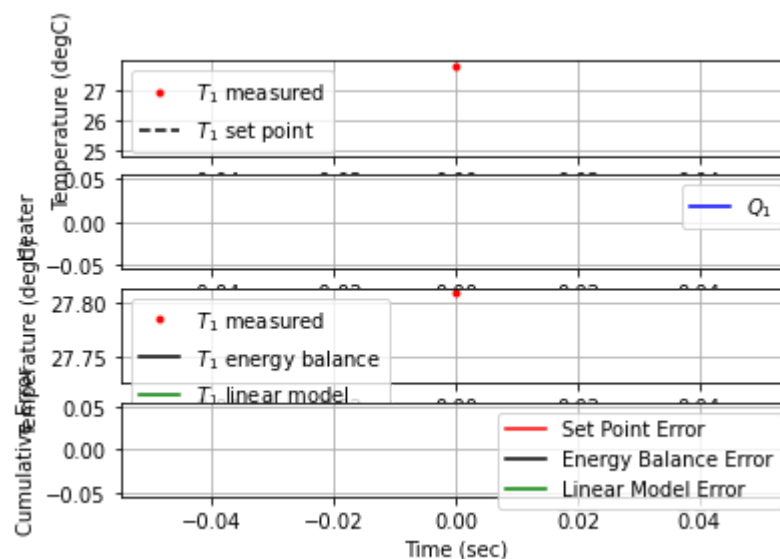
LED On

Running Main Loop. Ctrl-C to end.

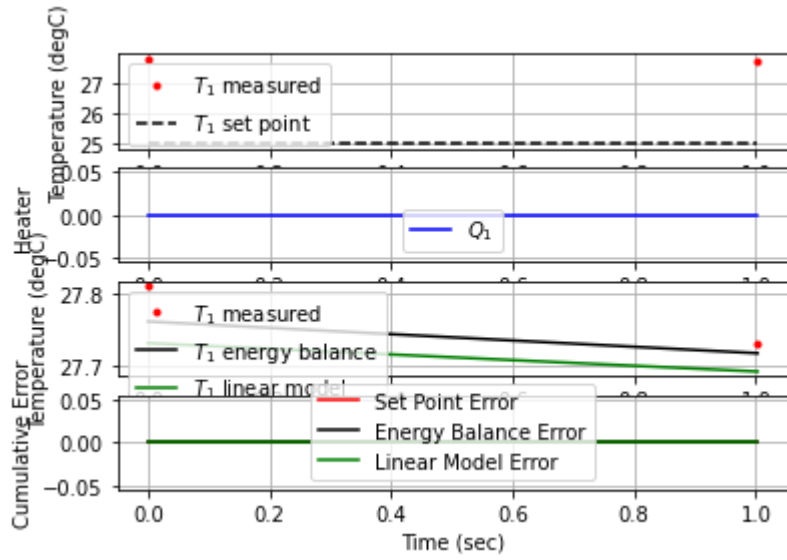
Time	SP	PV	Q1	= P	+ I	+ D
0.0	25.00	27.81	0.00	0.00	0.00	0.00

<Figure size 720x504 with 0 Axes>

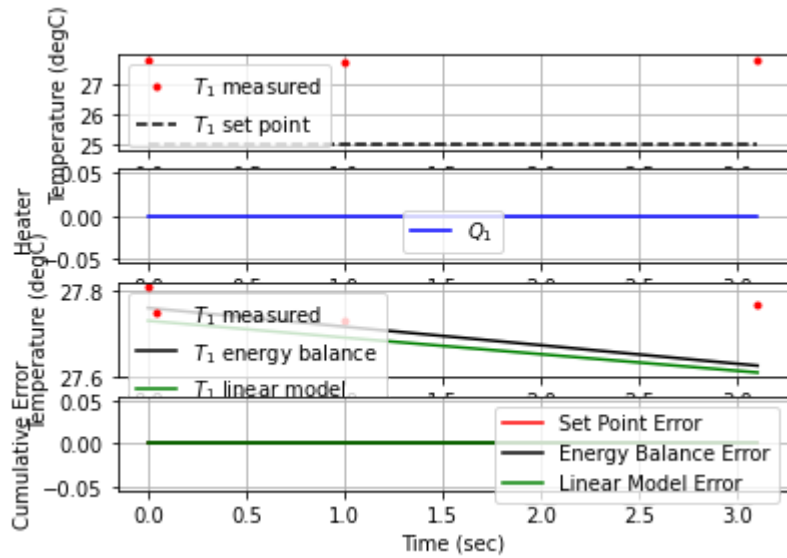
1.0	25.00	27.73	0.00	-27.30	0.00	0.80
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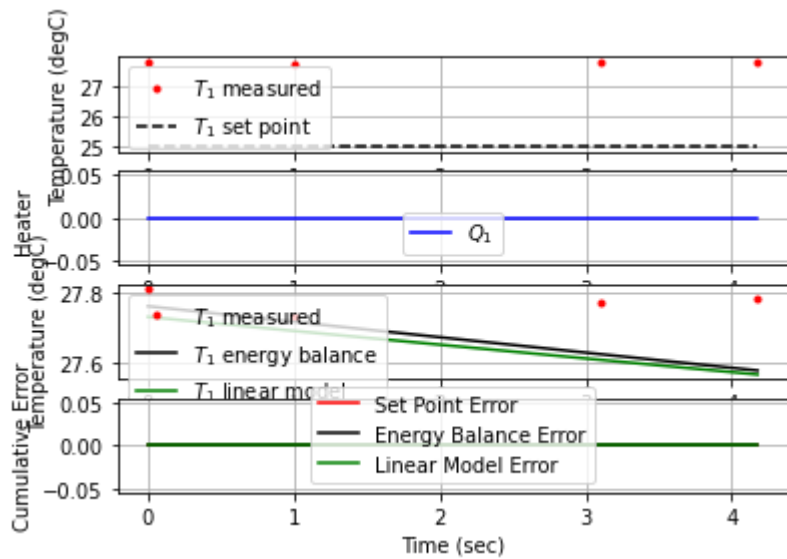
3.1	25.00	27.77	0.00	-27.70	0.00	-0.19
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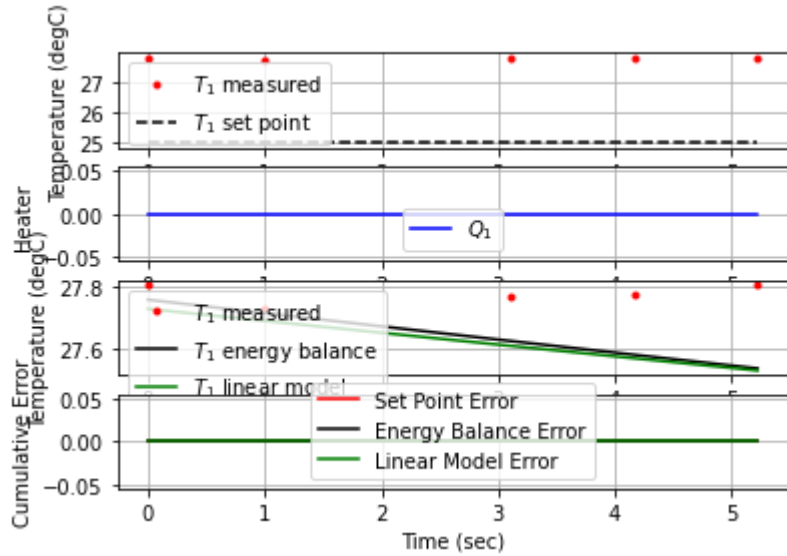
4.2 25.00 27.78 0.00 -27.80 0.00 -0.09



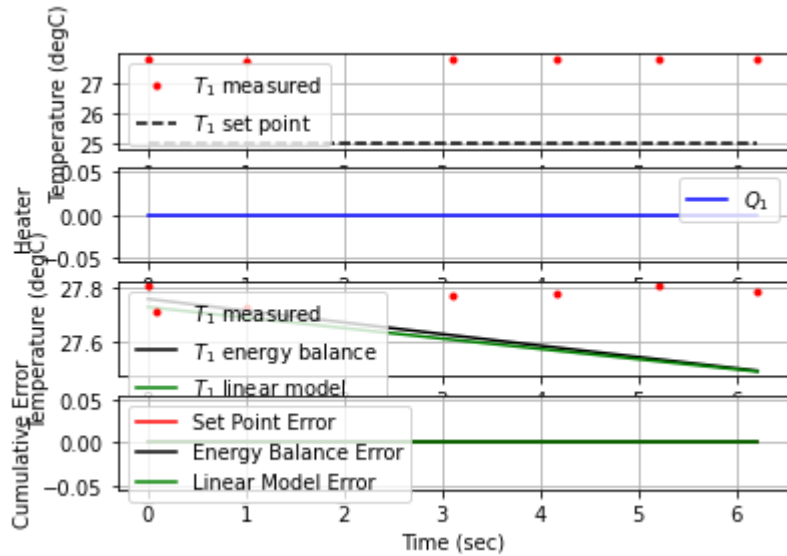
5.2 25.00 27.81 0.00 -28.10 0.00 -0.29



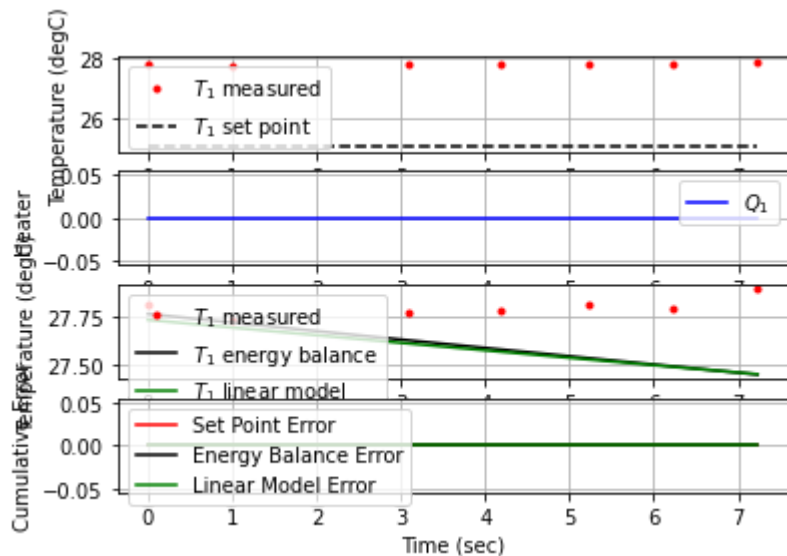
6.2 25.00 27.79 0.00 -27.90 0.00 0.20



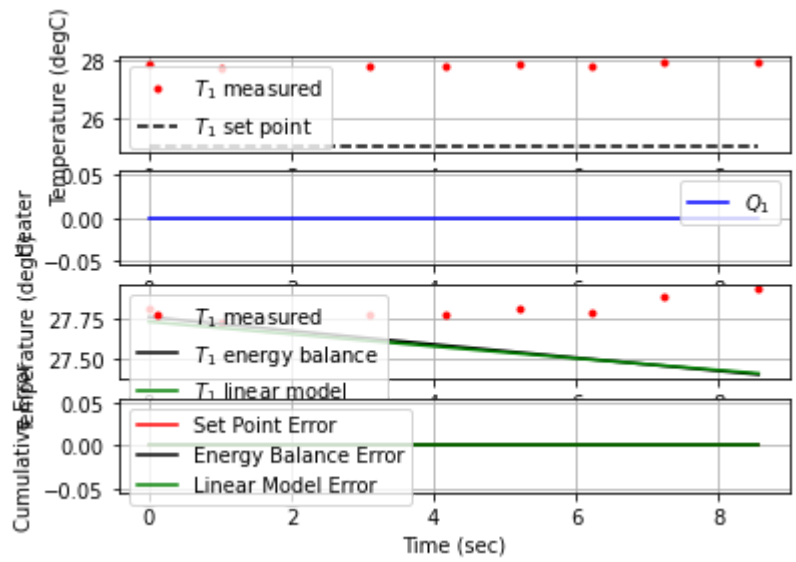
7.2 25.00 27.89 0.00 -28.90 0.00 -0.99



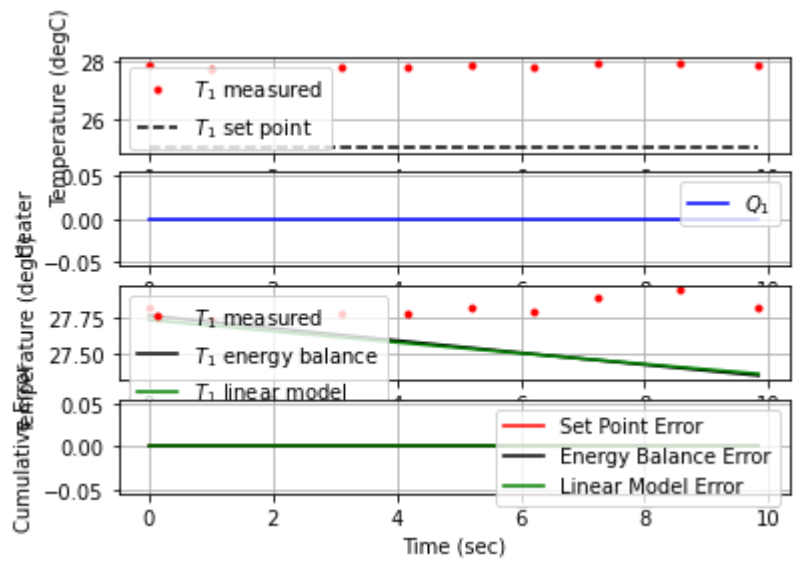
8.6 25.00 27.94 0.00 -29.40 0.00 -0.37



9.8 25.00 27.82 0.00 -28.20 0.00 0.95

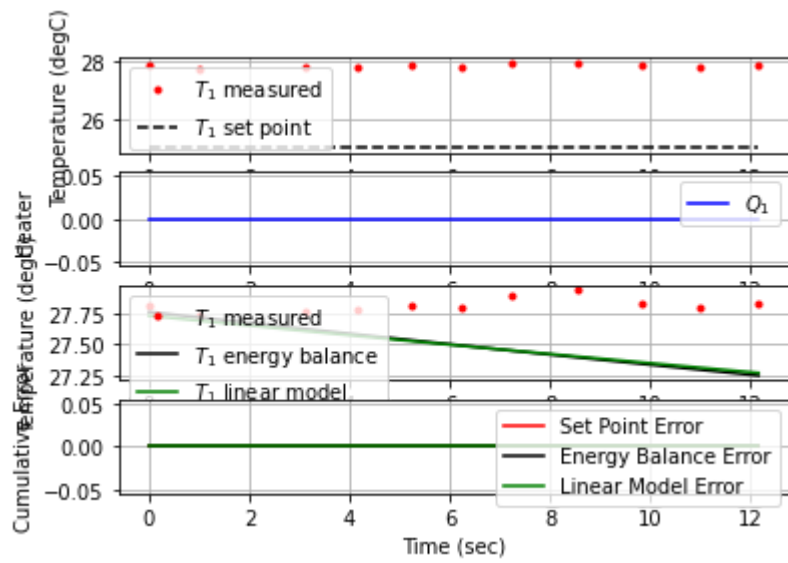


11.0 25.00 27.79 0.00 -27.90 0.00 0.26

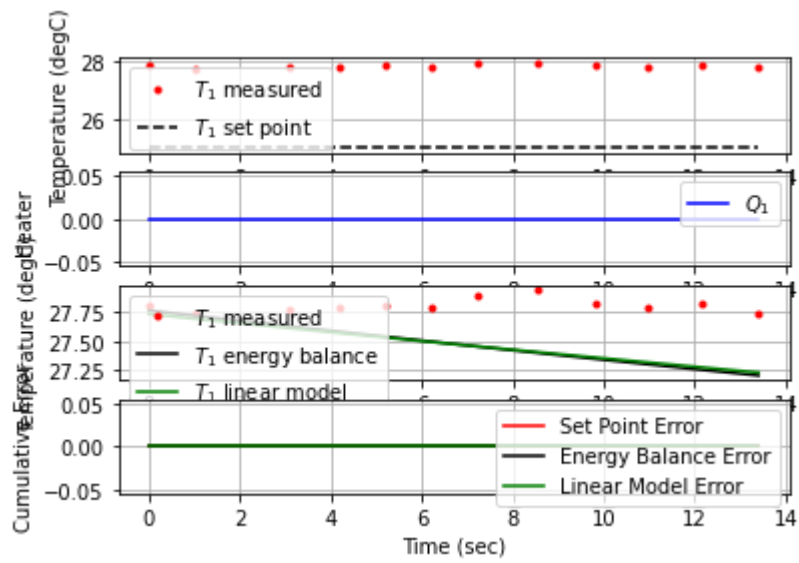


12.2 25.00 27.82 0.00 -28.20 0.00 -0.26

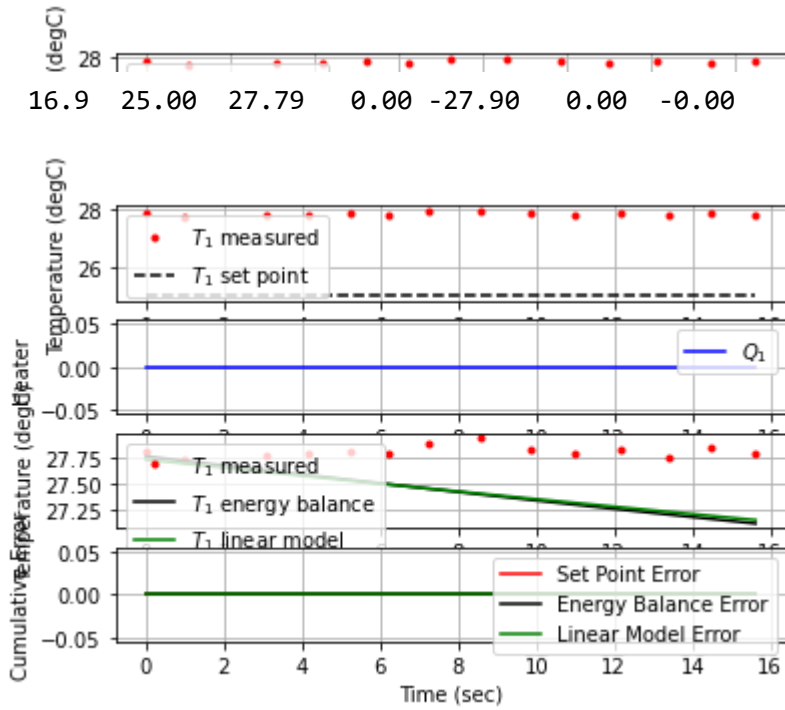
13.4 25.00 27.74 0.00 -27.40 0.00 0.64



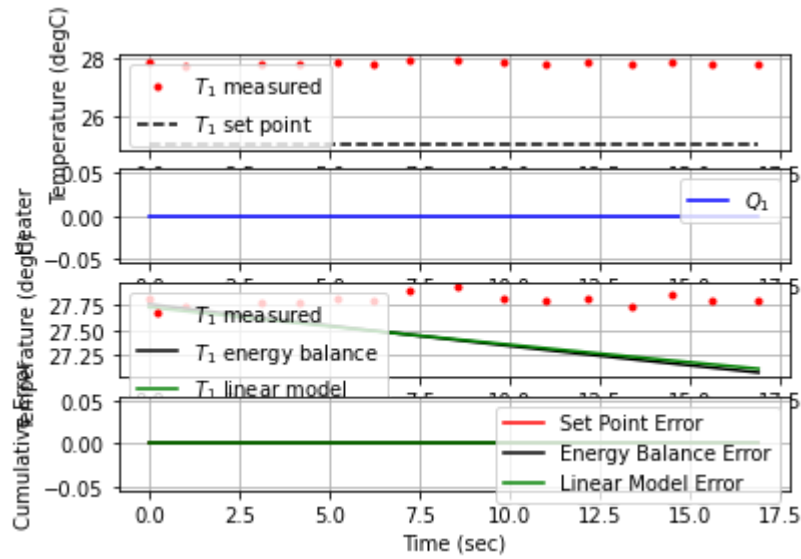
14.5 25.00 27.85 0.00 -28.50 0.00 -1.02



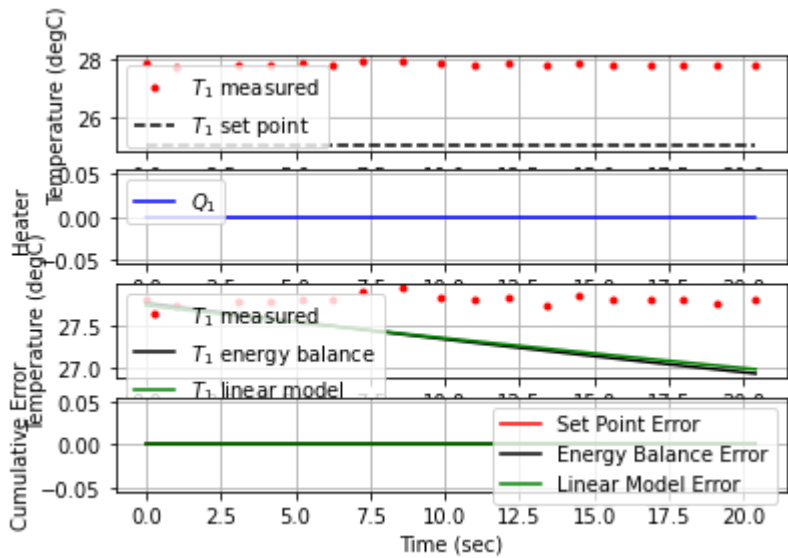
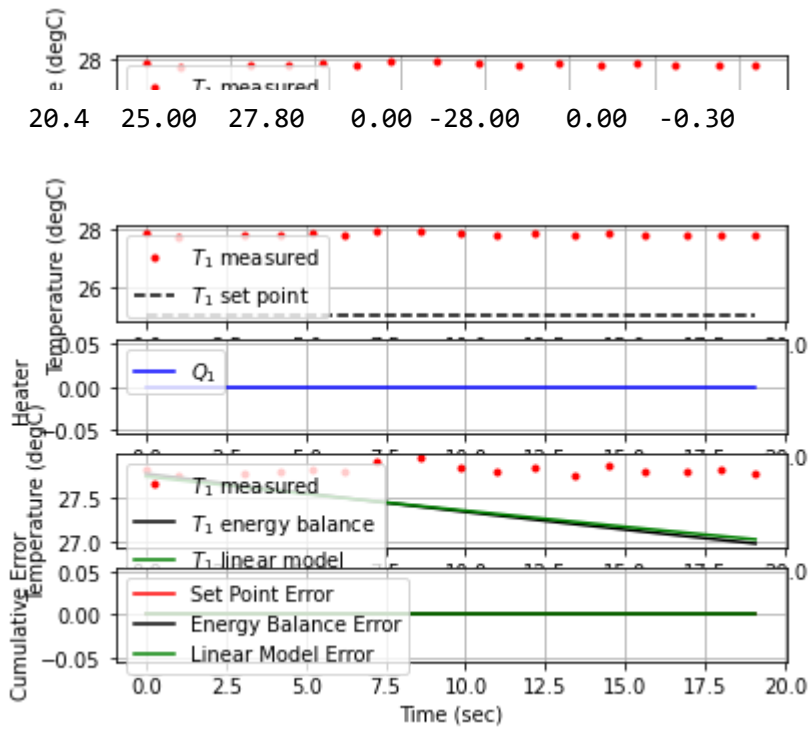
15.6 25.00 27.79 0.00 -27.90 0.00 0.53



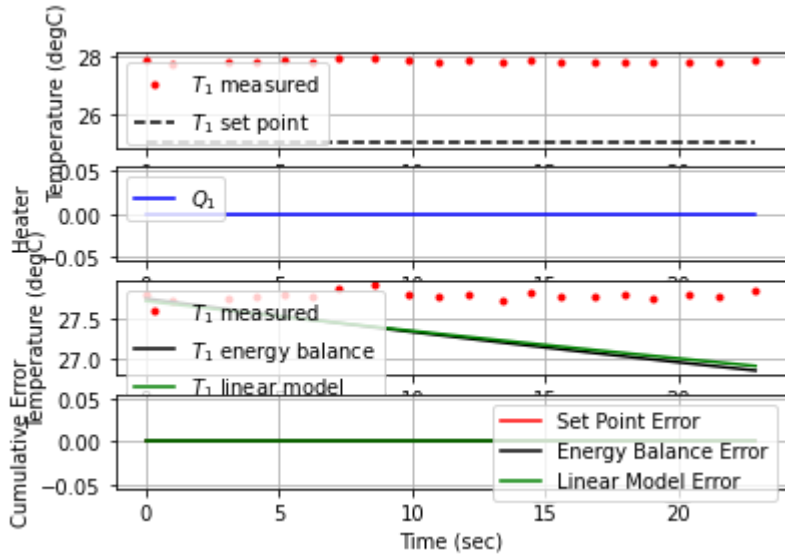
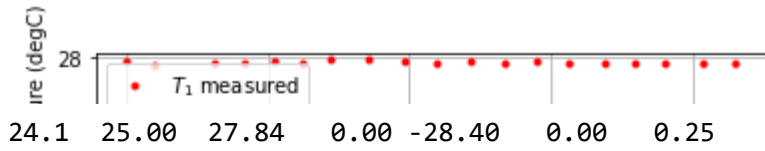
18.0 25.00 27.80 0.00 -28.00 0.00 -0.09



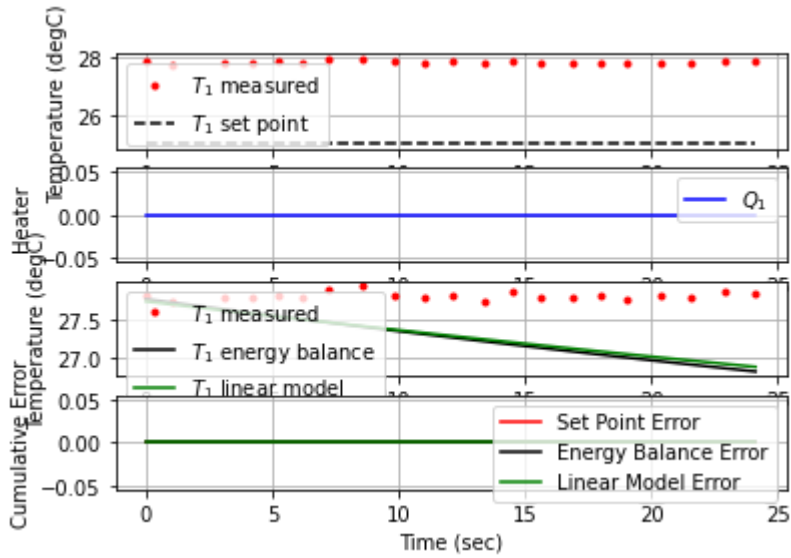
19.1 25.00 27.76 0.00 -27.60 0.00 0.37



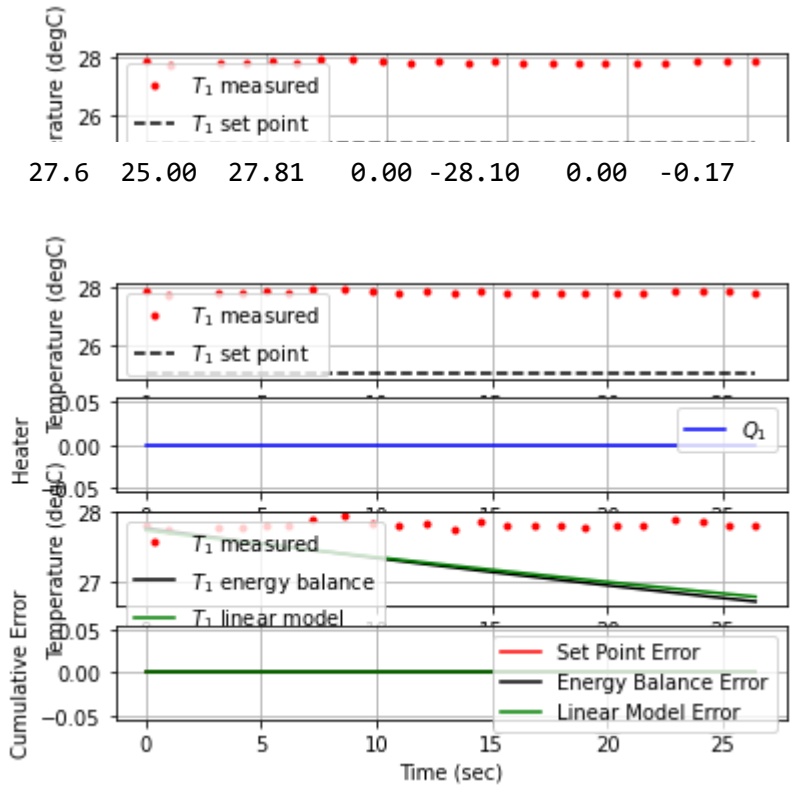
22.9 25.00 27.87 0.00 -28.70 0.00 -0.58



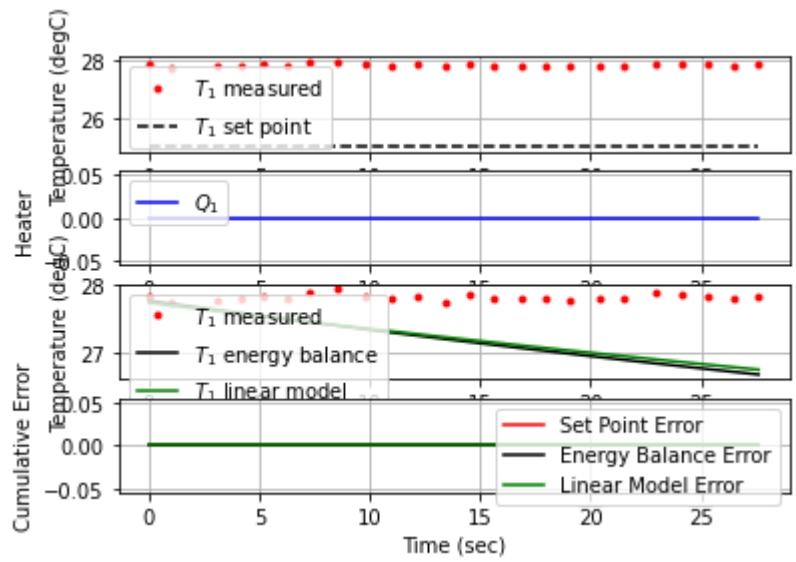
25.3 25.00 27.81 0.00 -28.10 0.00 0.25



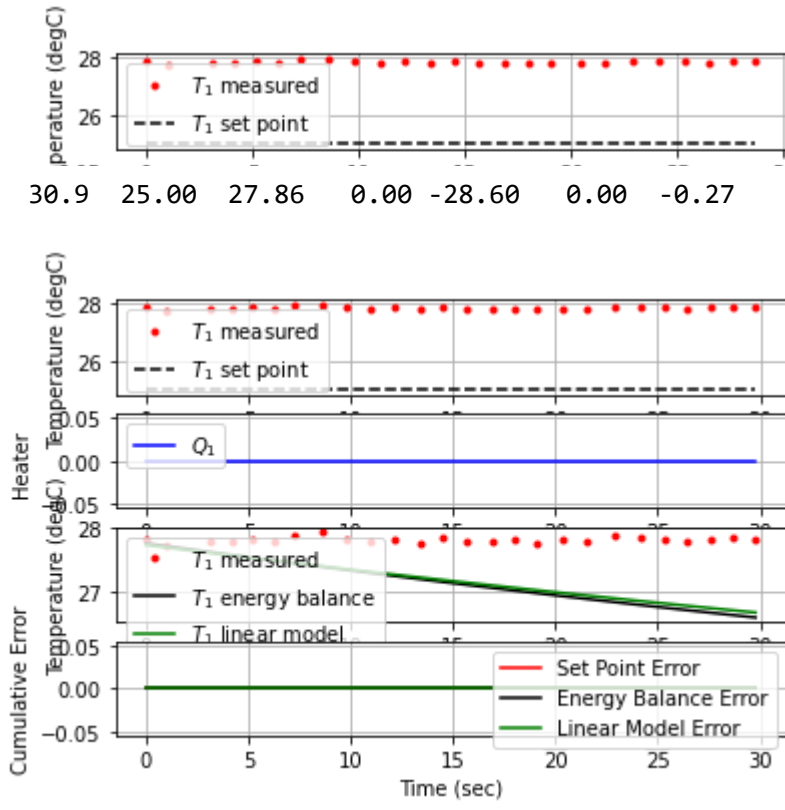
26.4 25.00 27.79 0.00 -27.90 0.00 0.18



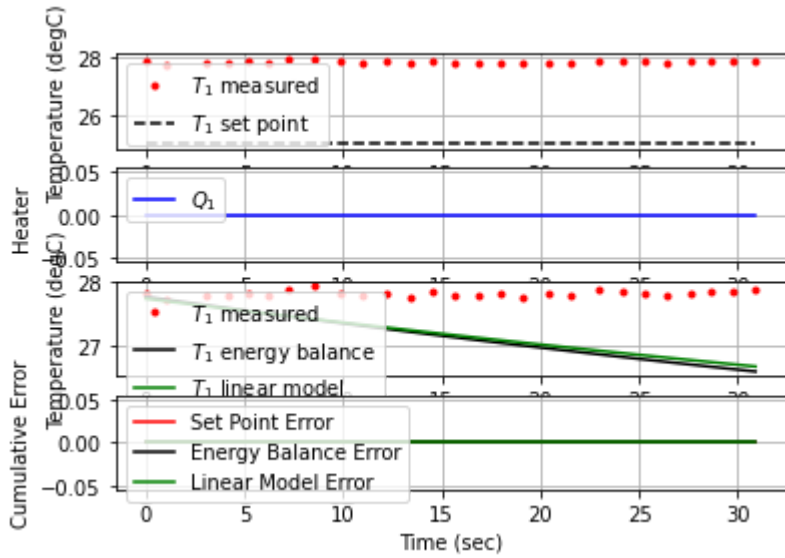
28.7 25.00 27.85 0.00 -28.50 0.00 -0.38



29.8 25.00 27.83 0.00 -28.30 0.00 0.18

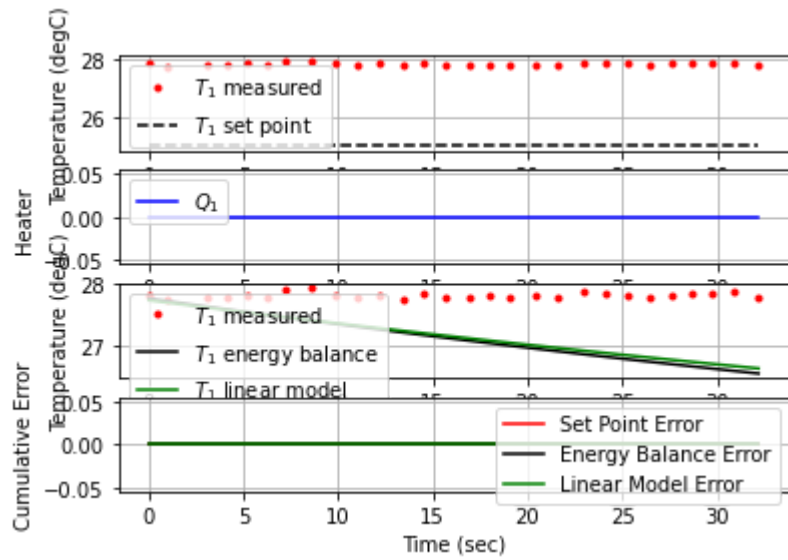


30.9 25.00 27.86 0.00 -28.60 0.00 -0.27

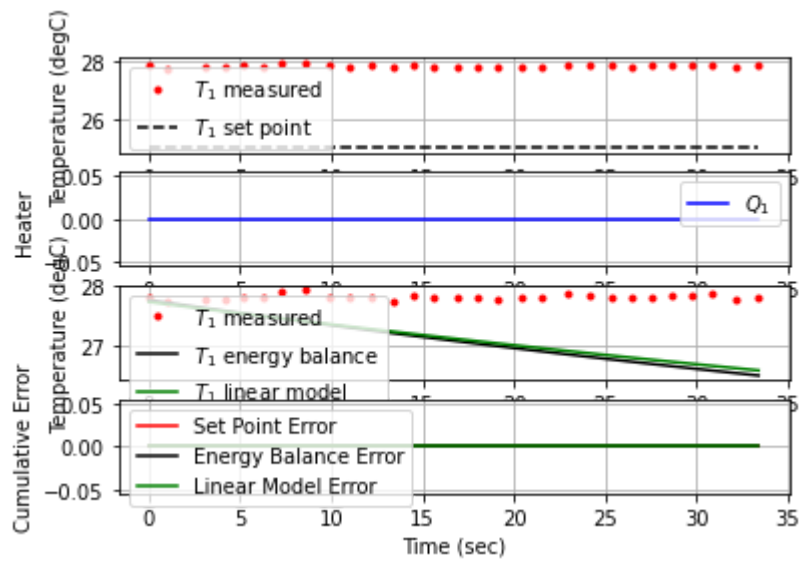


32.2 25.00 27.78 0.00 -27.80 0.00 0.62

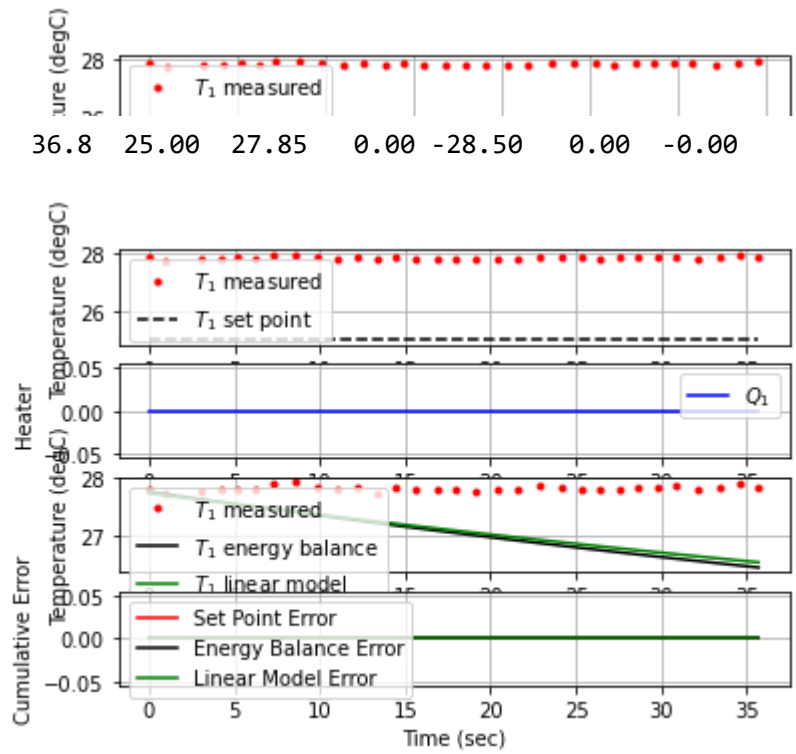
33.4 25.00 27.82 0.00 -28.20 0.00 -0.33



34.6 25.00 27.89 0.00 -28.90 0.00 -0.58

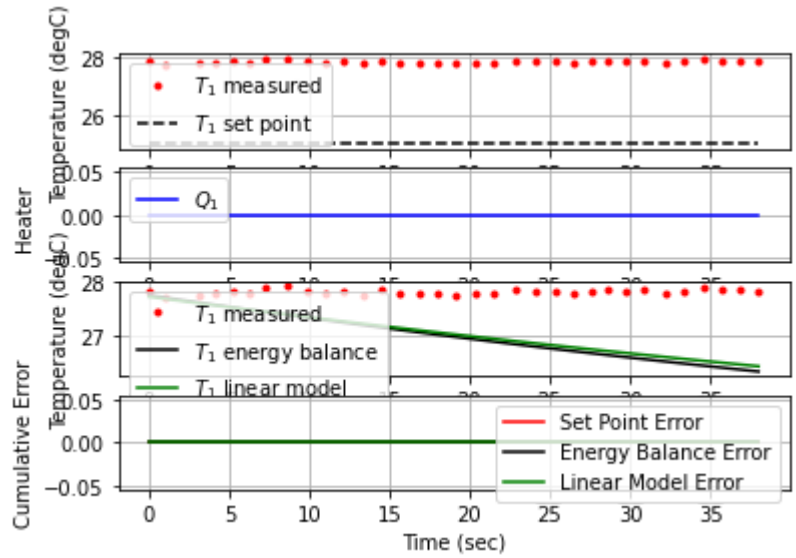


35.7 25.00 27.85 0.00 -28.50 0.00 0.38

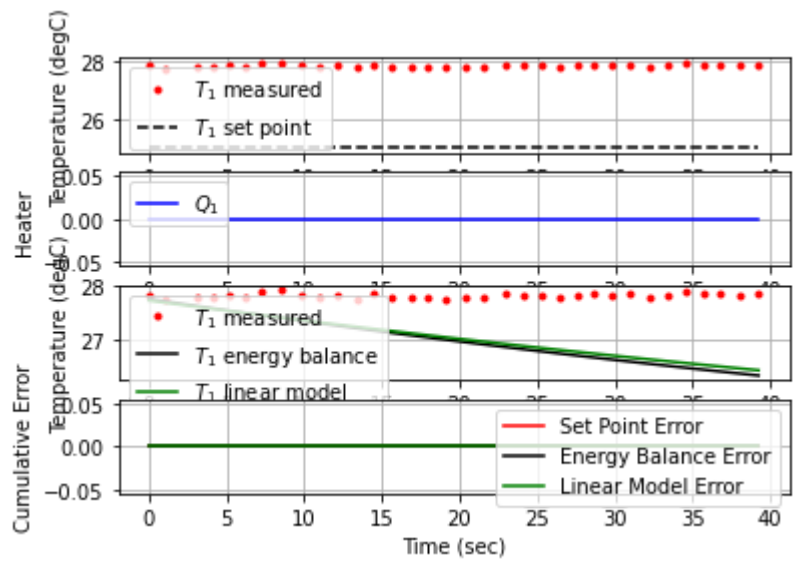


38.0 25.00 27.84 0.00 -28.40 0.00 0.08

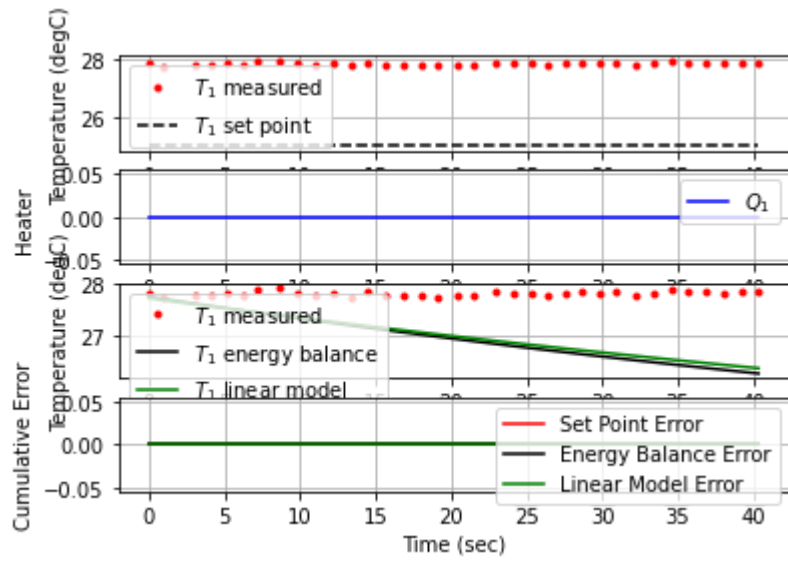
C) 39.2 25.00 27.85 0.00 -28.50 0.00 -0.08



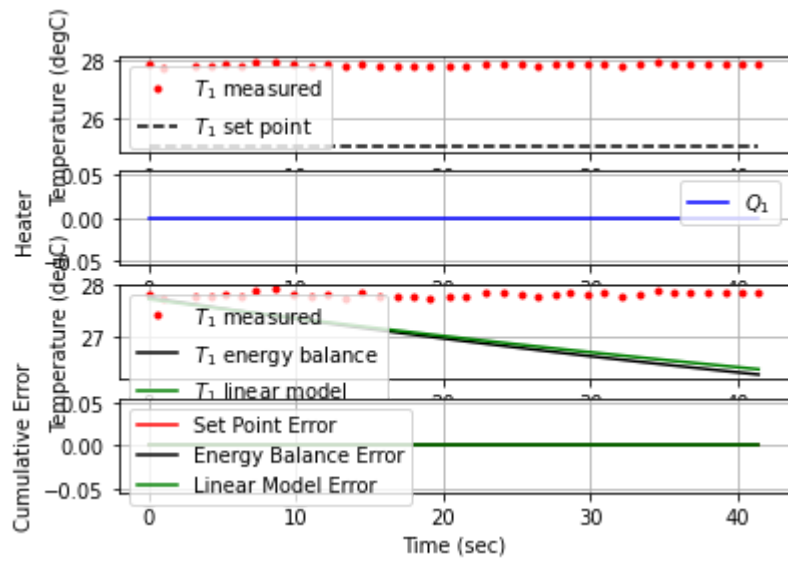
40.3 25.00 27.85 0.00 -28.50 0.00 -0.00



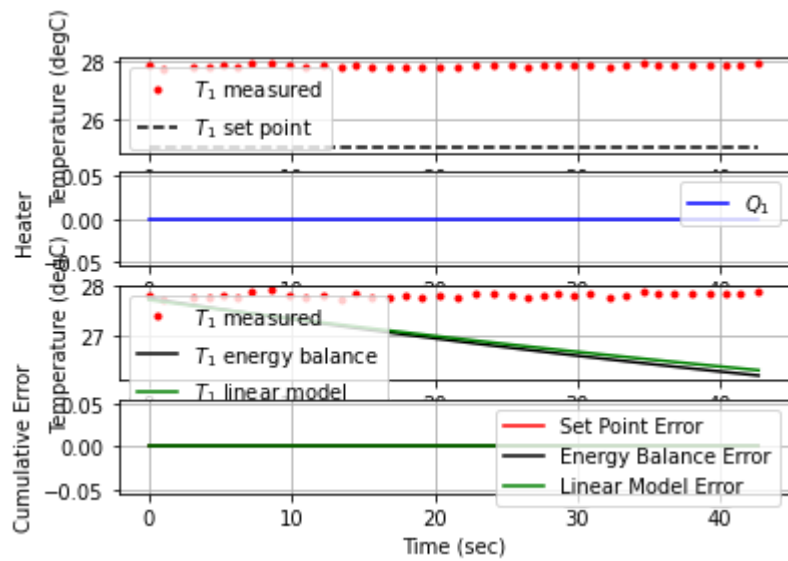
41.4 25.00 27.87 0.00 -28.70 0.00 -0.18



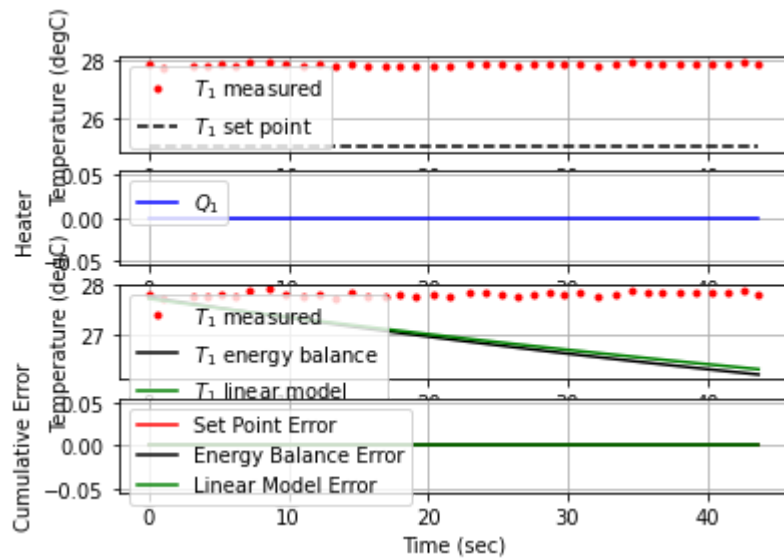
42.7 25.00 27.88 0.00 -28.80 0.00 -0.08



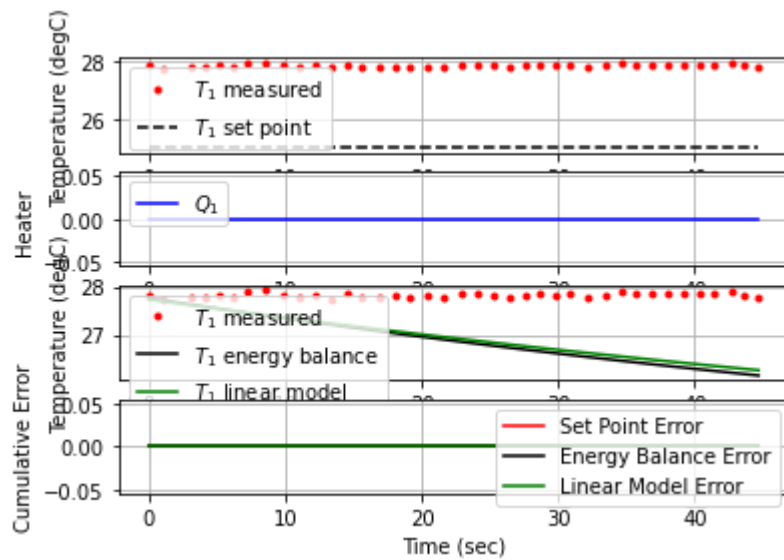
43.7 25.00 27.83 0.00 -28.30 0.00 0.50



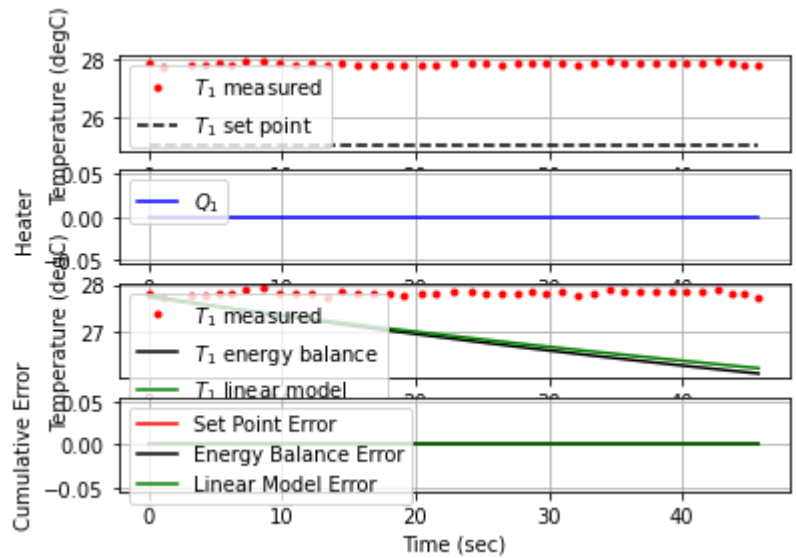
44.7 25.00 27.79 0.00 -27.90 0.00 0.40



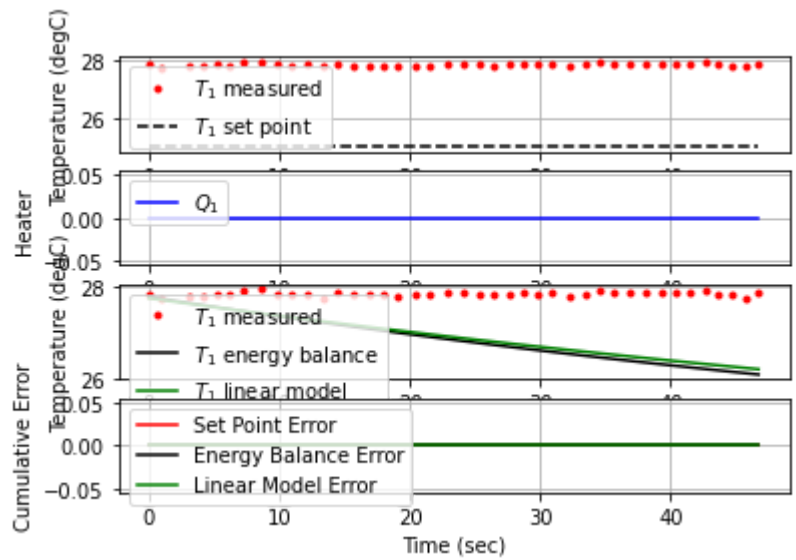
45.7 25.00 27.74 0.00 -27.40 0.00 0.47



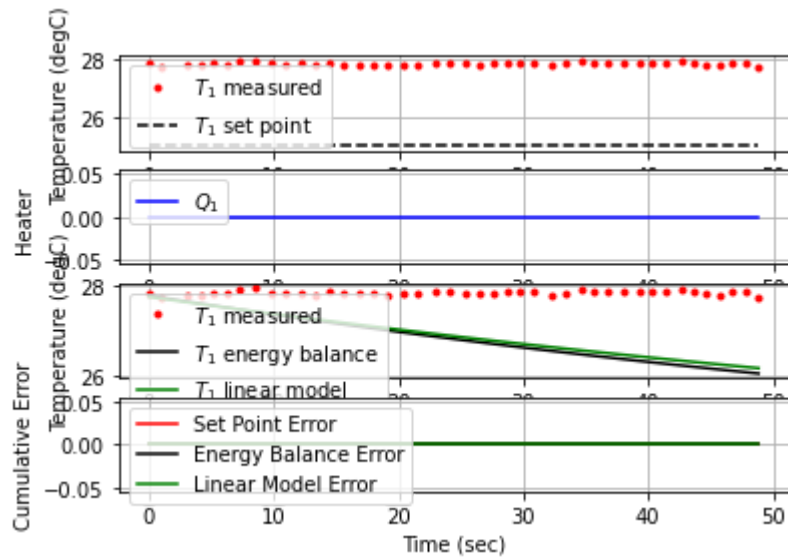
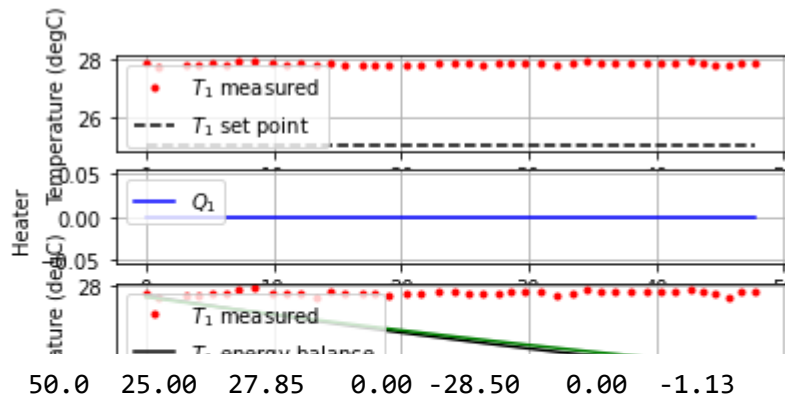
46.7 25.00 27.84 0.00 -28.40 0.00 -1.01



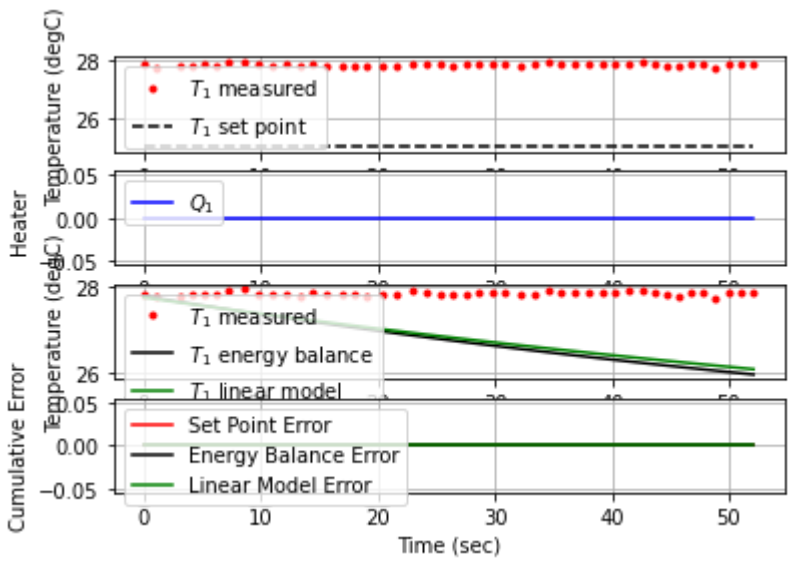
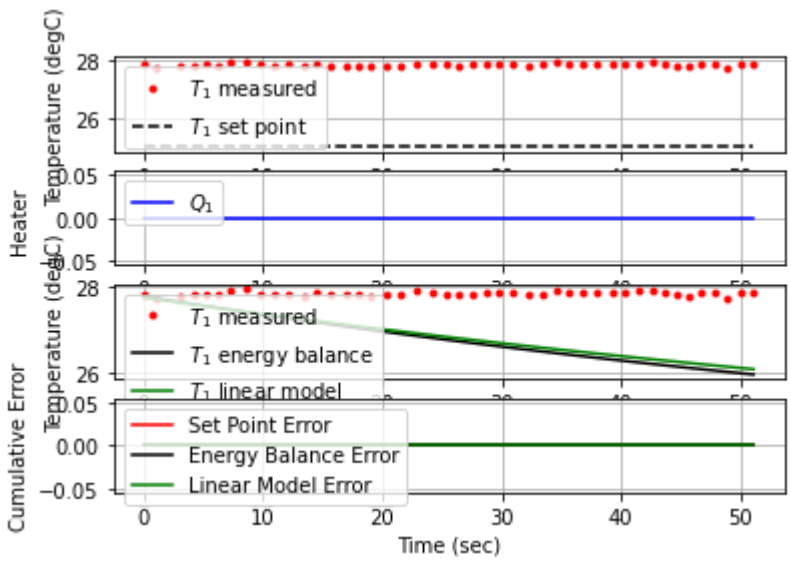
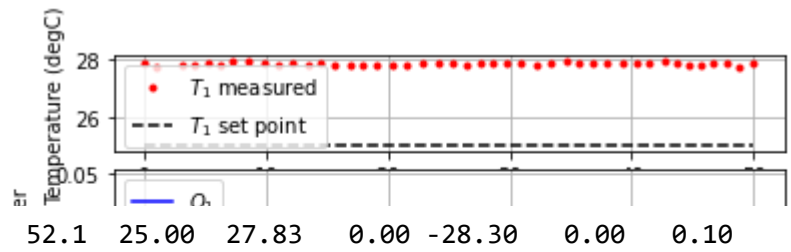
47.8 25.00 27.85 0.00 -28.50 0.00 -0.09



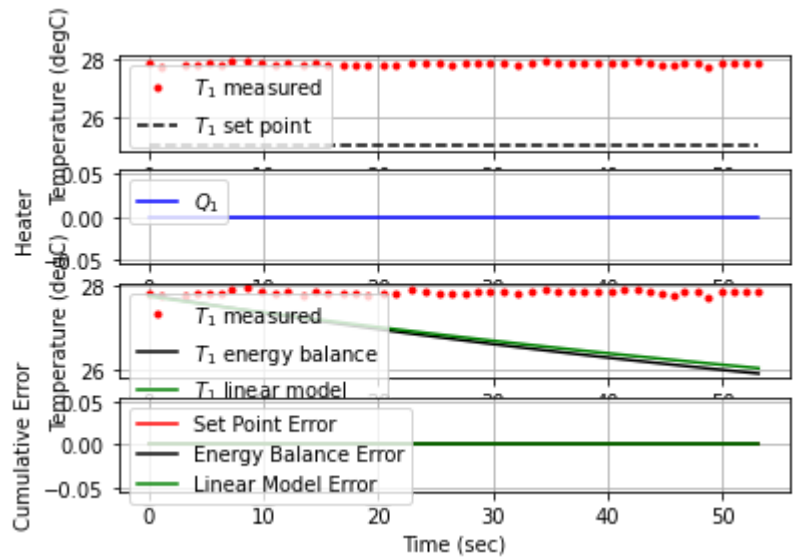
48.8 25.00 27.72 0.00 -27.20 0.00 1.28



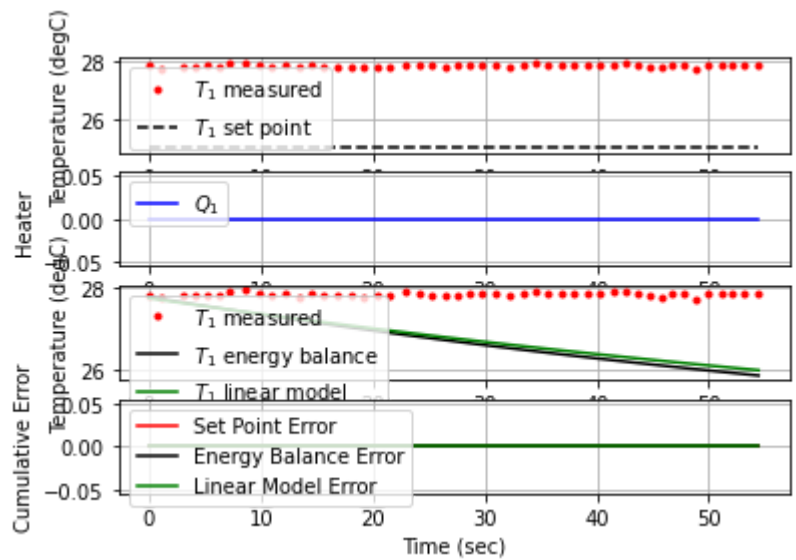
51.1 25.00 27.84 0.00 -28.40 0.00 0.09



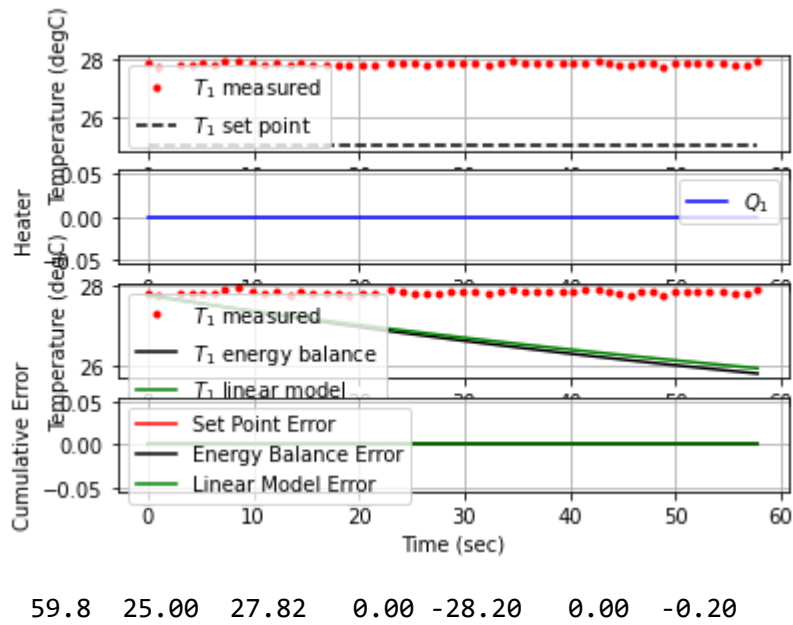
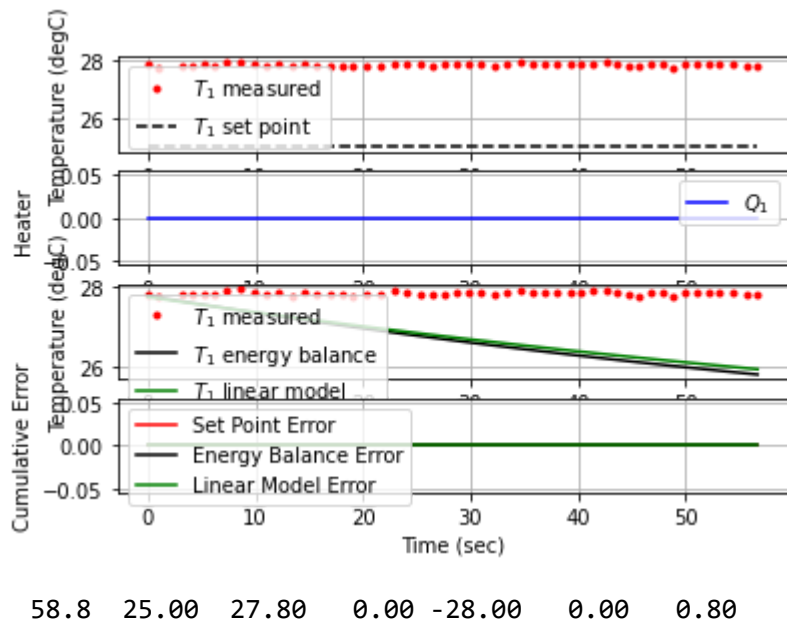
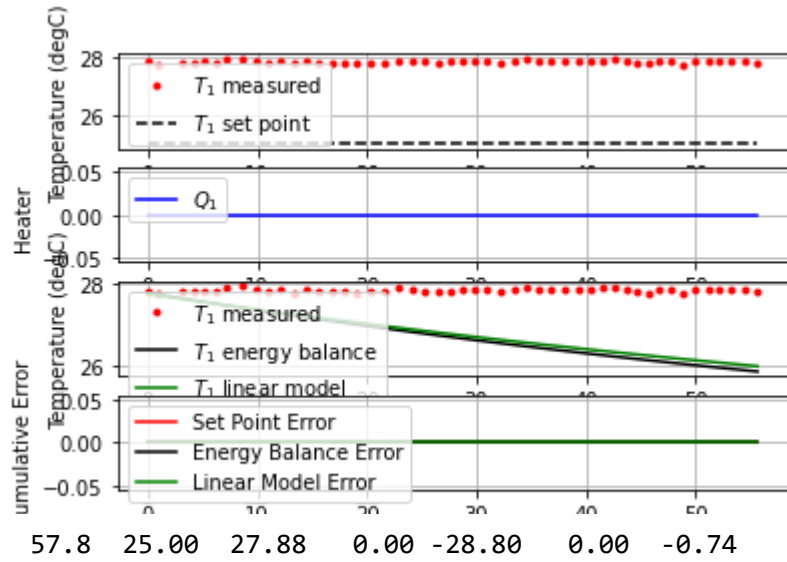
54.4 25.00 27.85 0.00 -28.50 0.00 -0.16

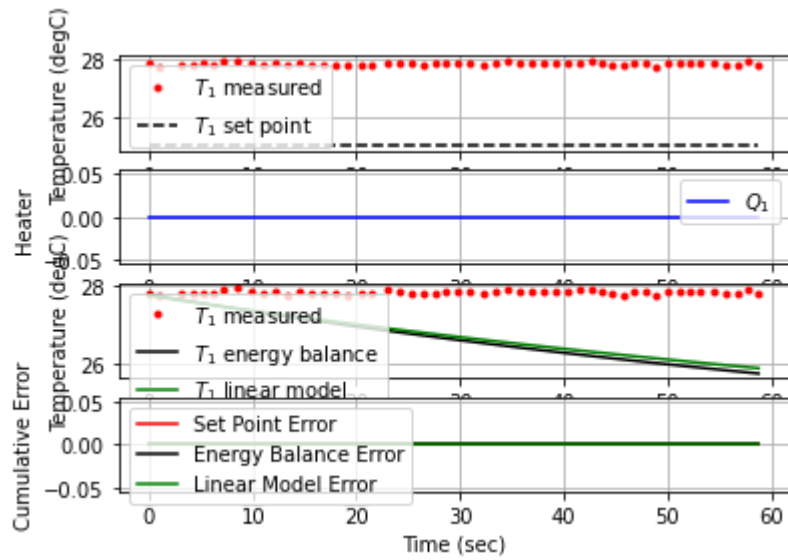


55.6 25.00 27.79 0.00 -27.90 0.00 0.50

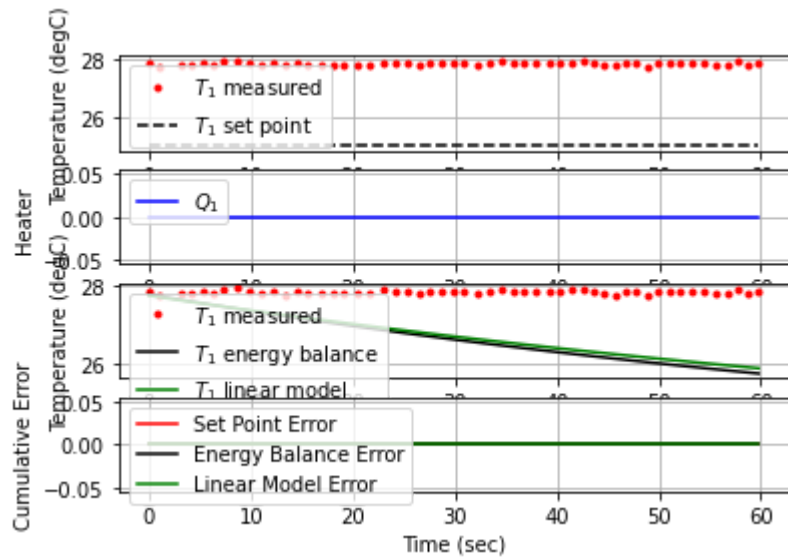


56.7 25.00 27.80 0.00 -28.00 0.00 -0.10

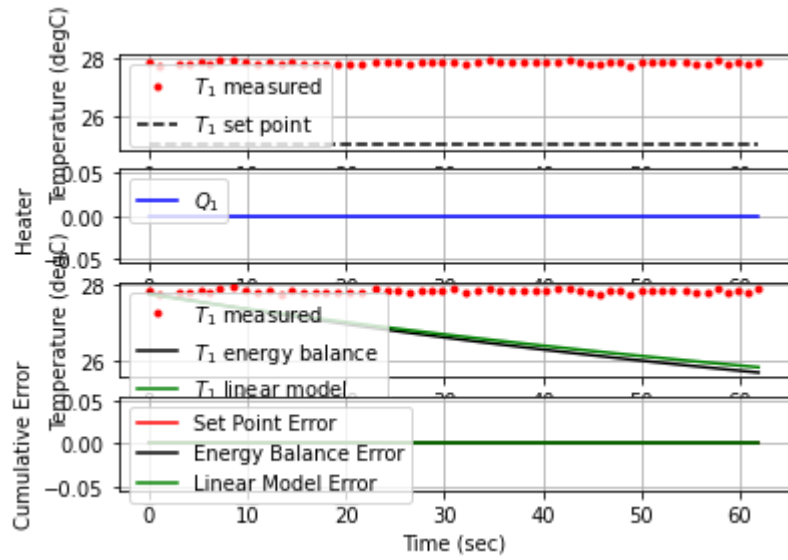
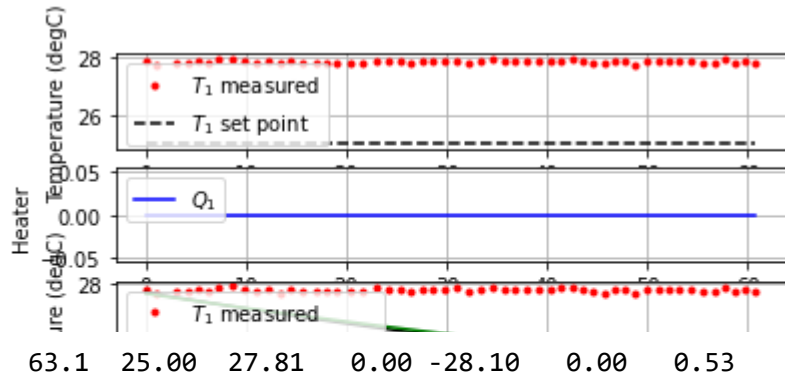




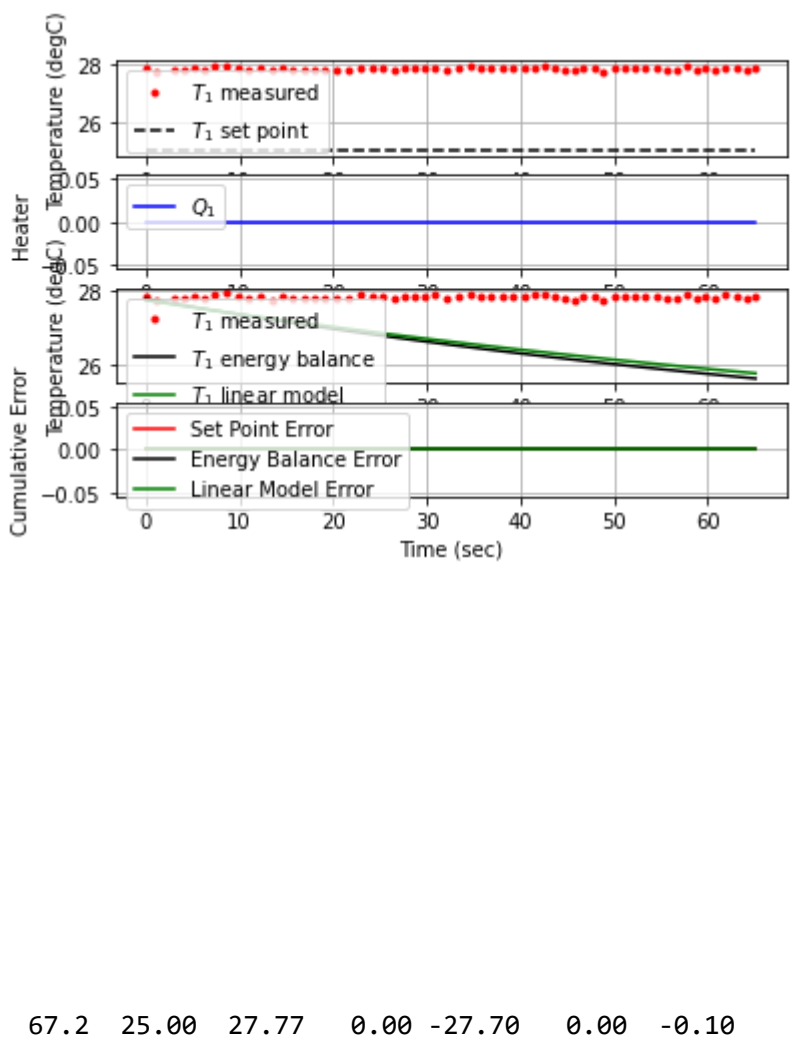
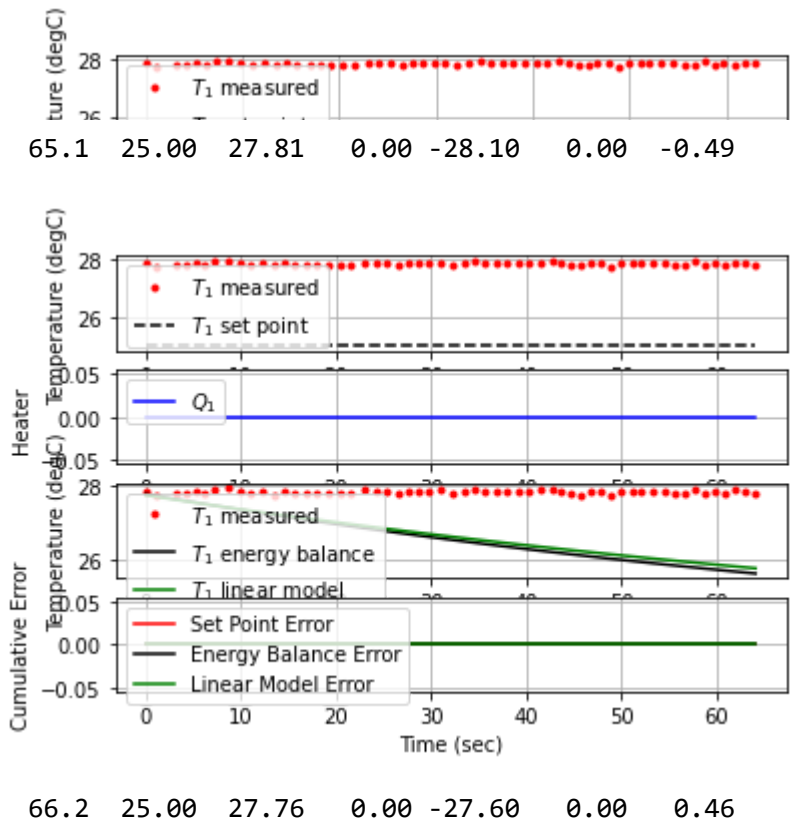
60.8 25.00 27.80 0.00 -28.00 0.00 0.19

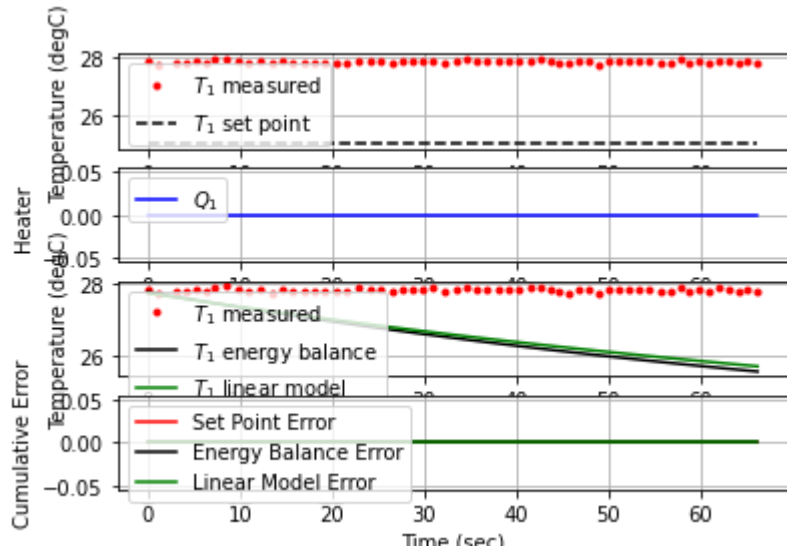


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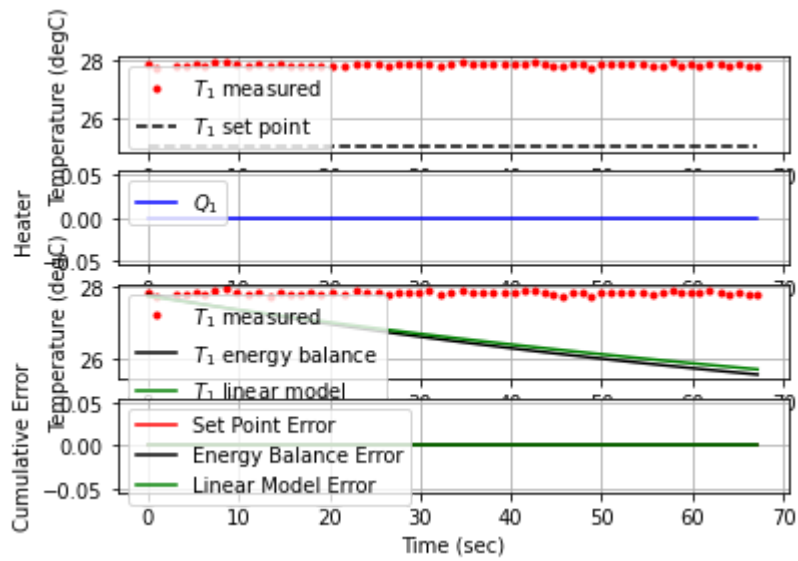


64.1 25.00 27.76 0.00 -27.60 0.00 0.49

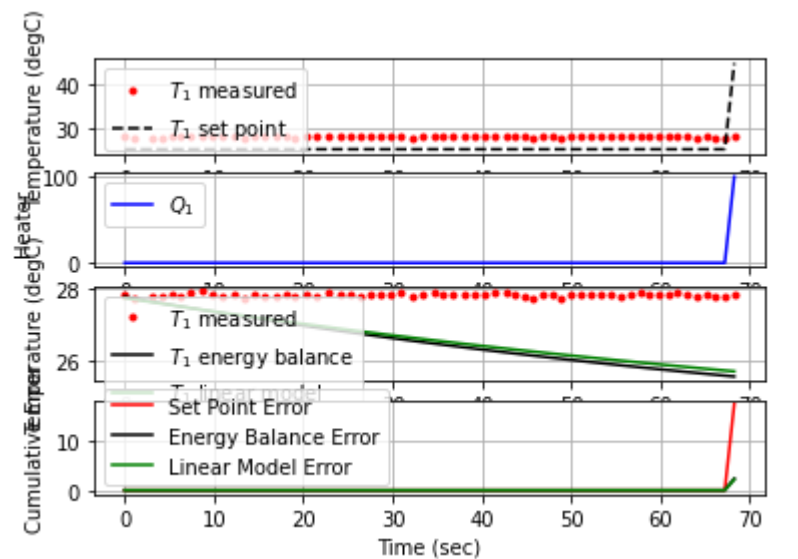




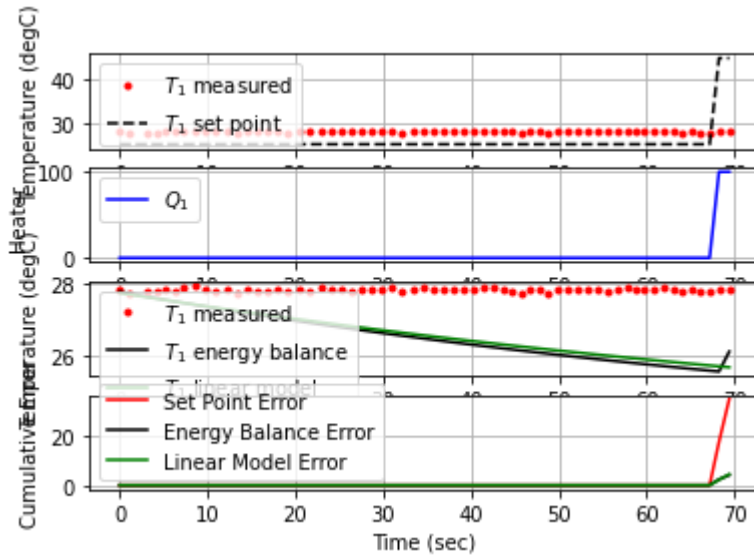
68.2 45.00 27.82 100.00 171.80 0.00 -0.47



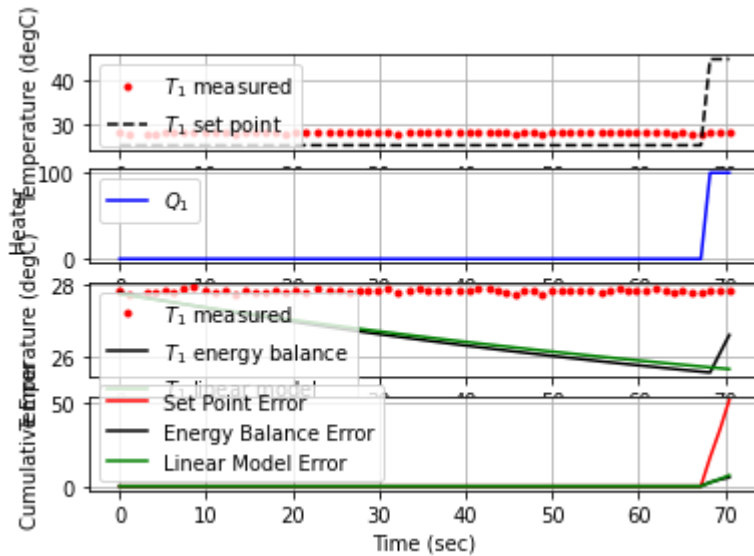
69.4 45.00 27.84 100.00 171.60 0.00 -0.17



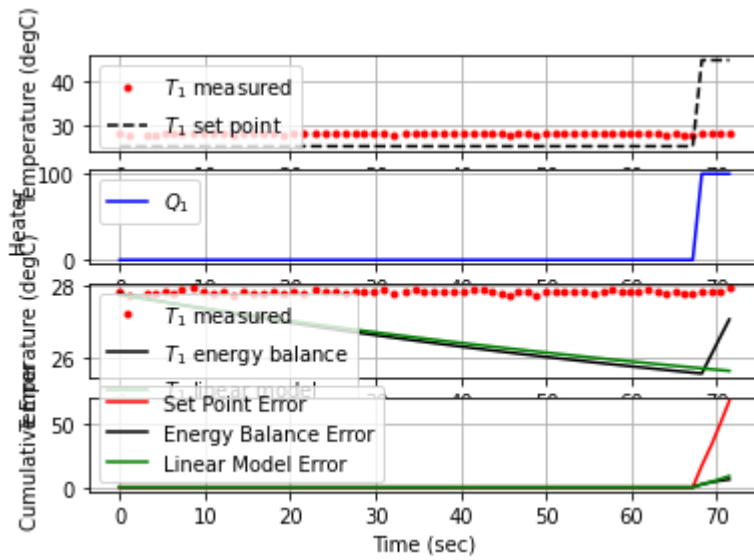
70.5 45.00 27.80 100.00 172.00 0.00 0.38



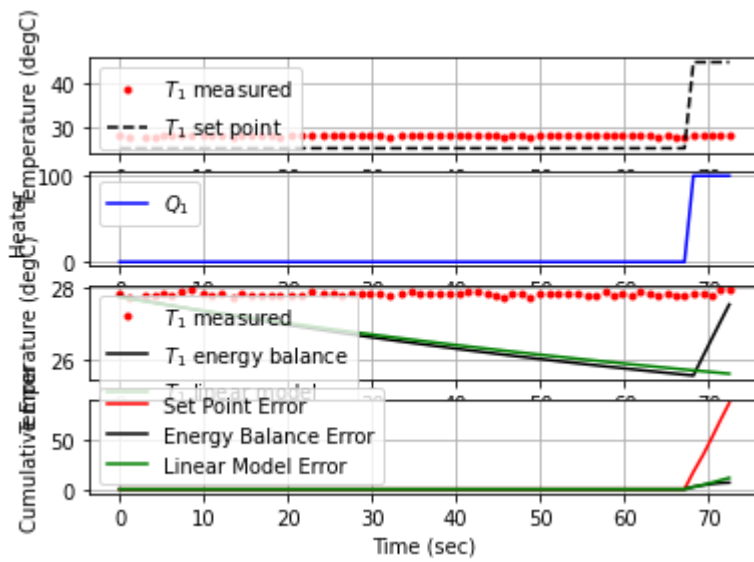
71.5 45.00 27.92 100.00 170.80 0.00 -1.20



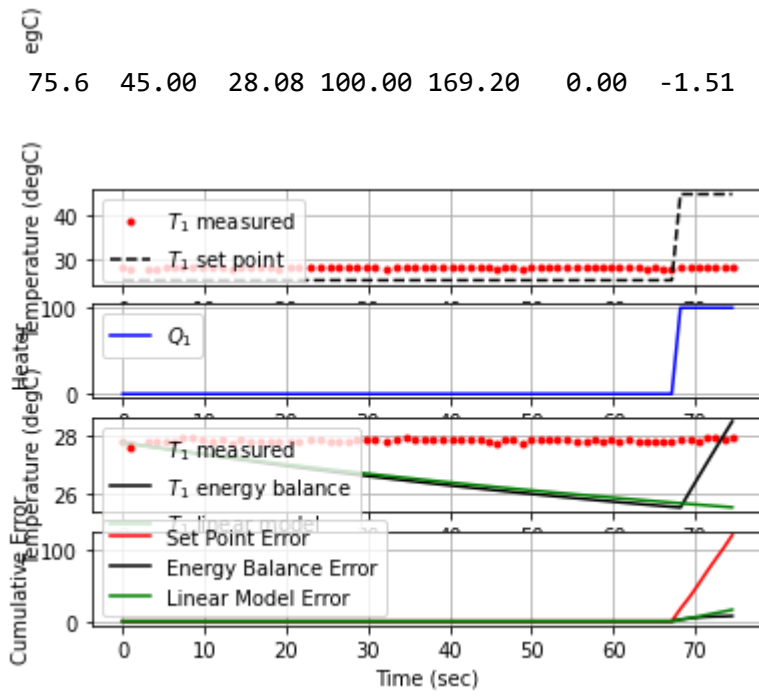
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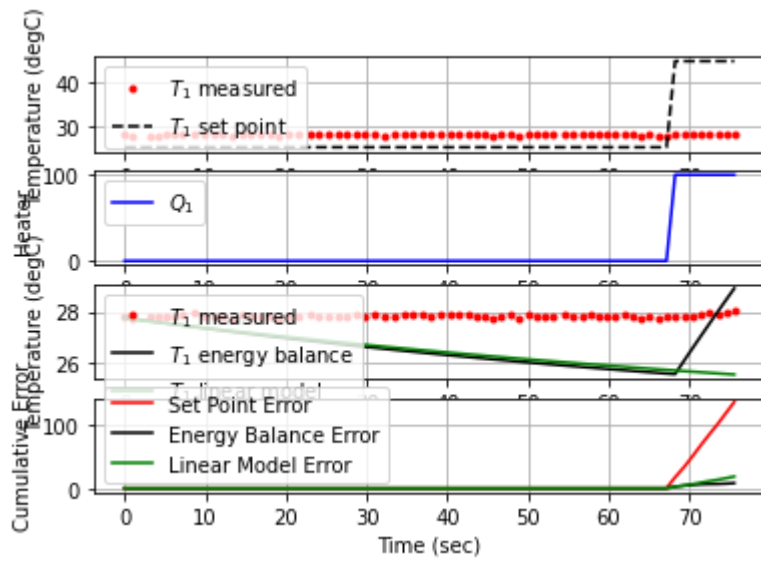
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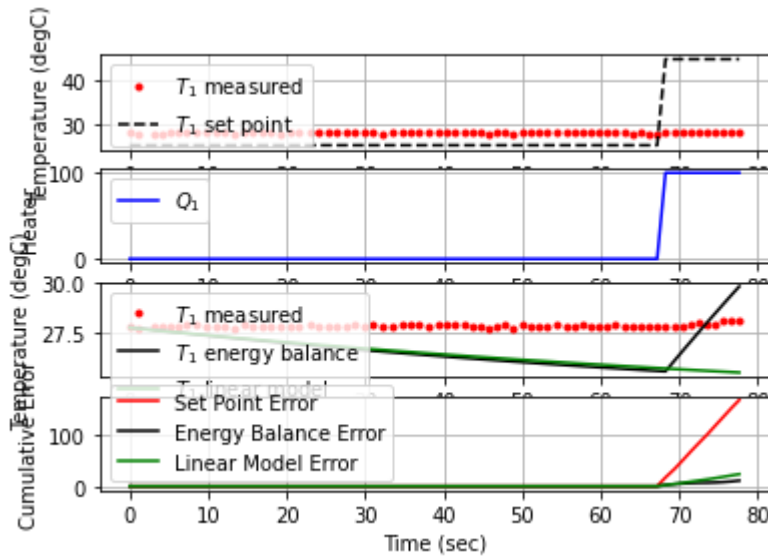
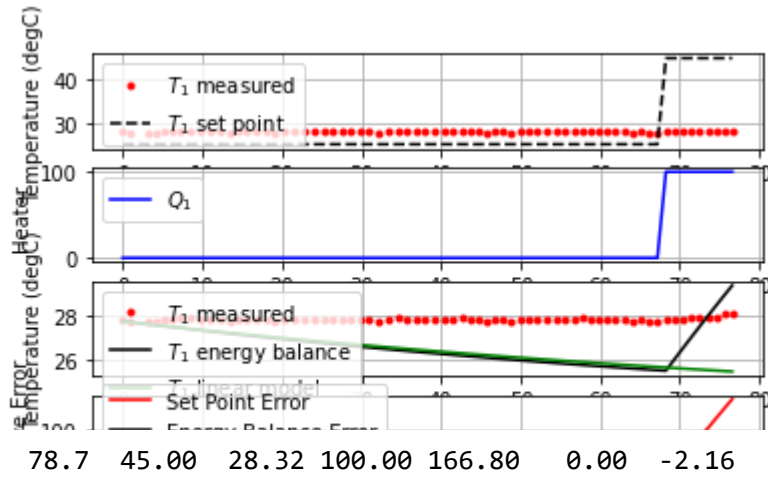
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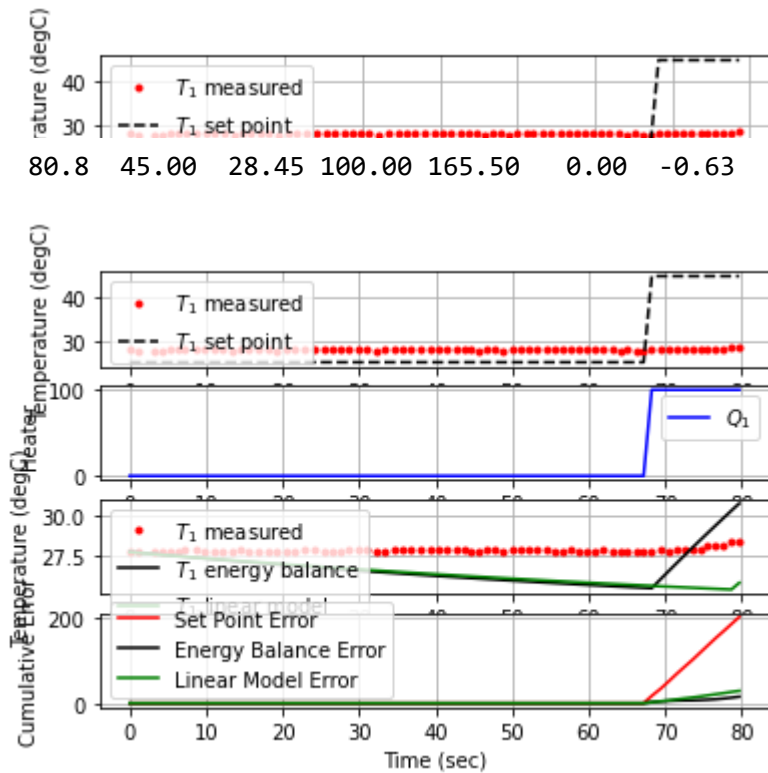
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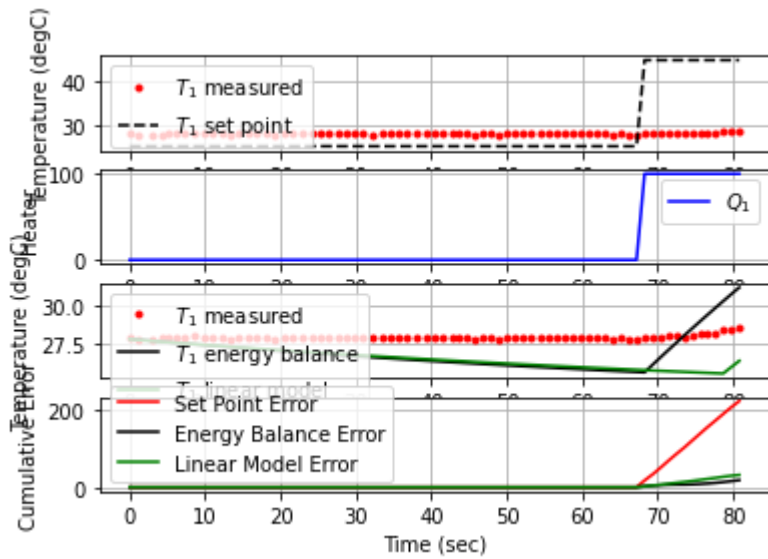
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79.7 45.00 28.38 100.00 166.20 0.00 -0.58

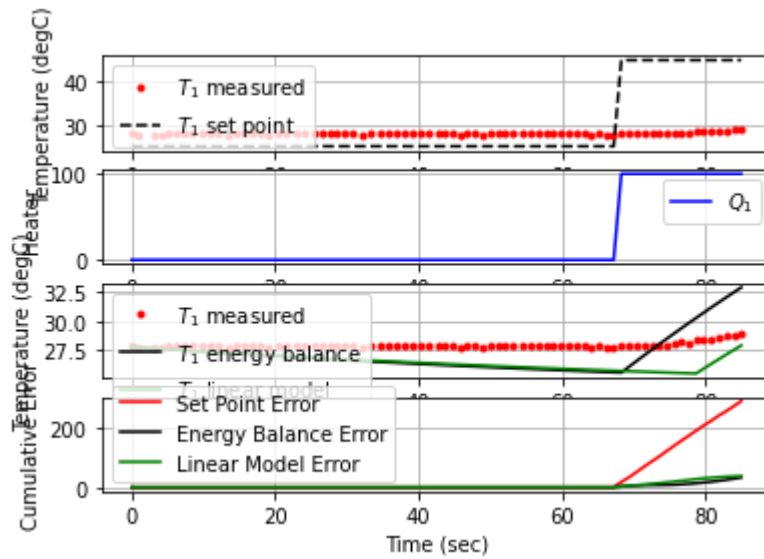


81.8 45.00 28.52 100.00 164.80 0.00 -0.69

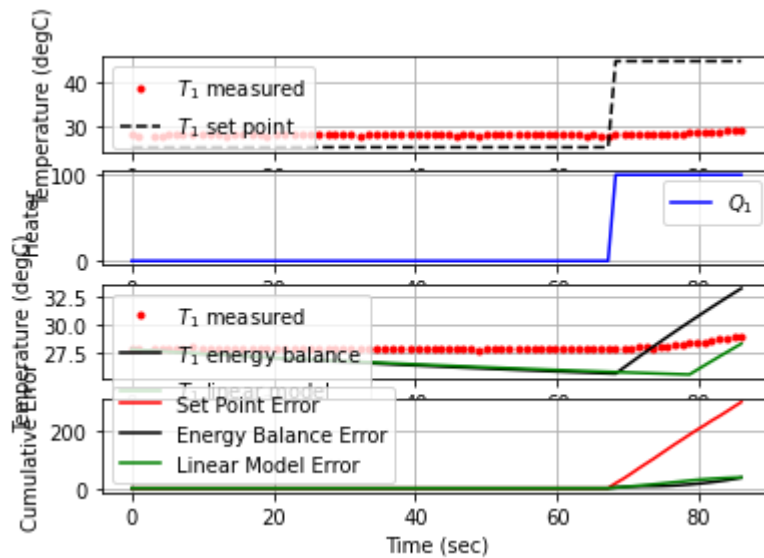


82.9 45.00 28.67 100.00 163.30 0.00 -1.33

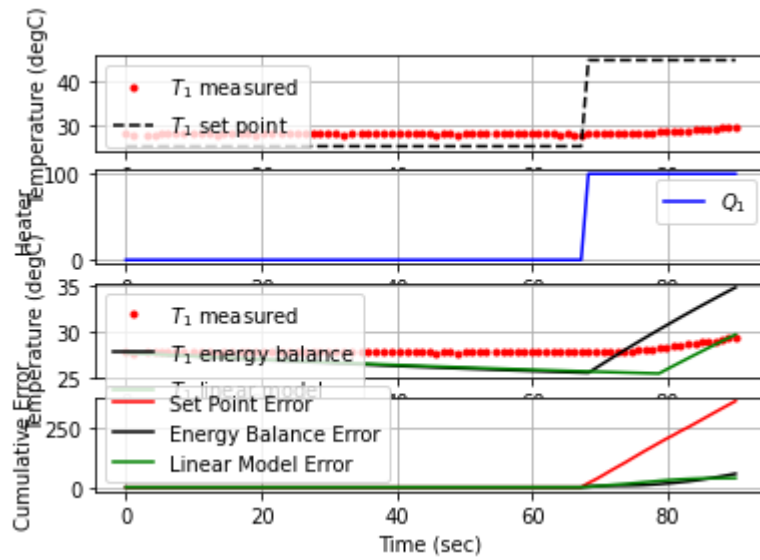
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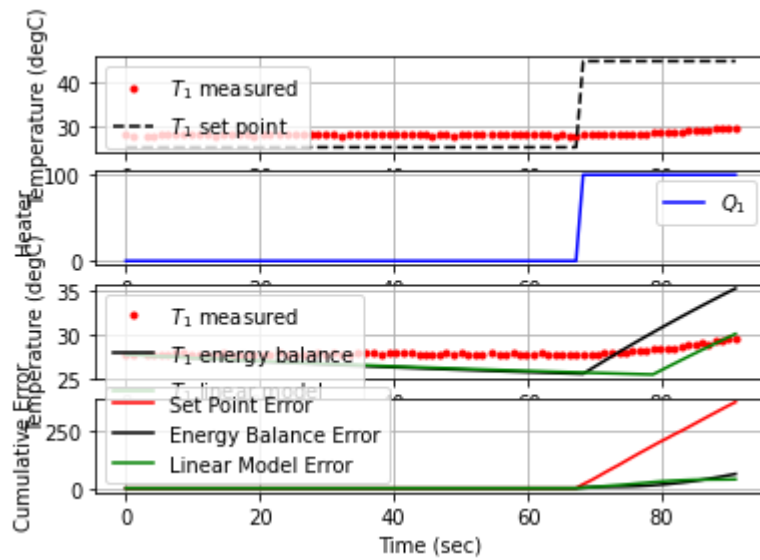
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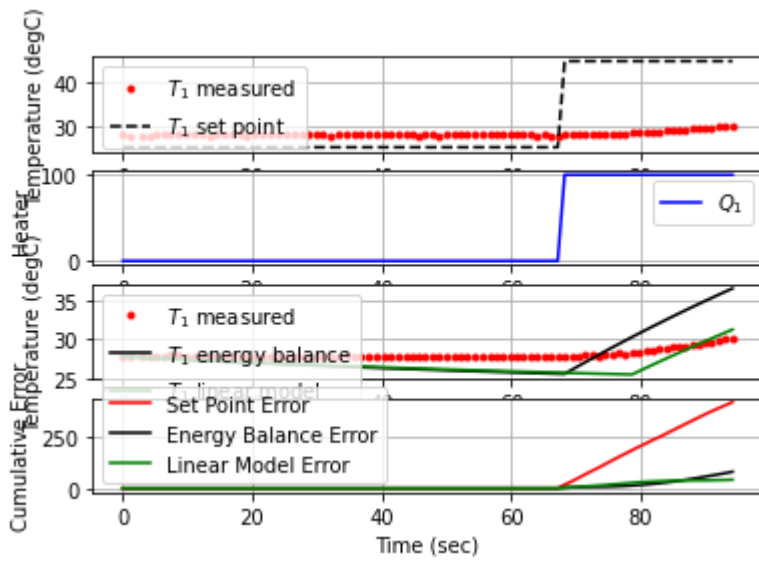
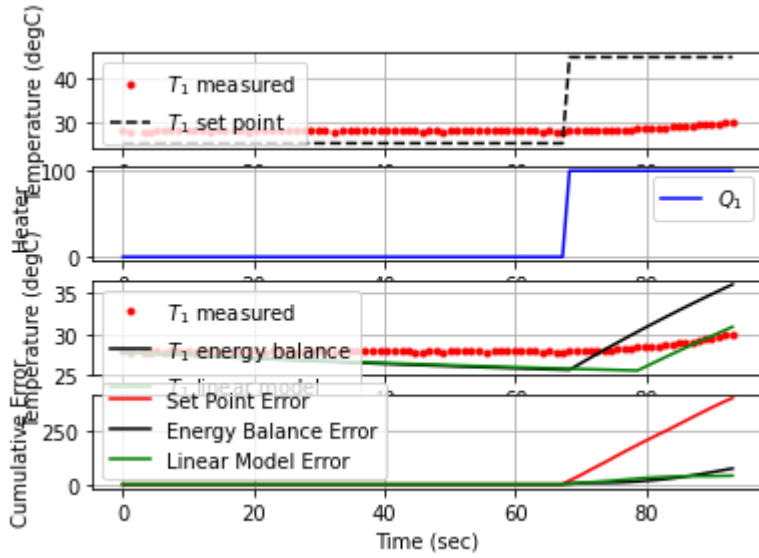
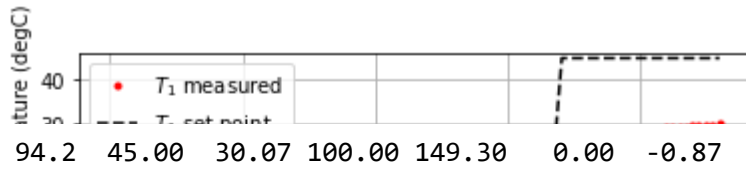
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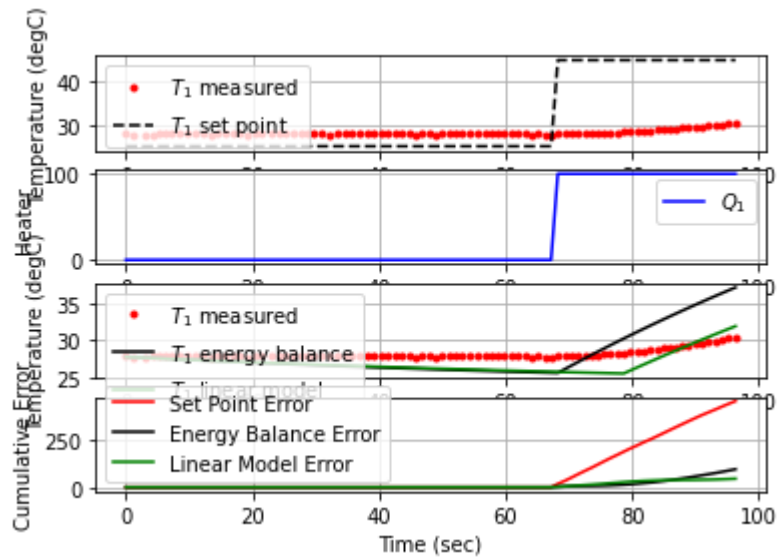
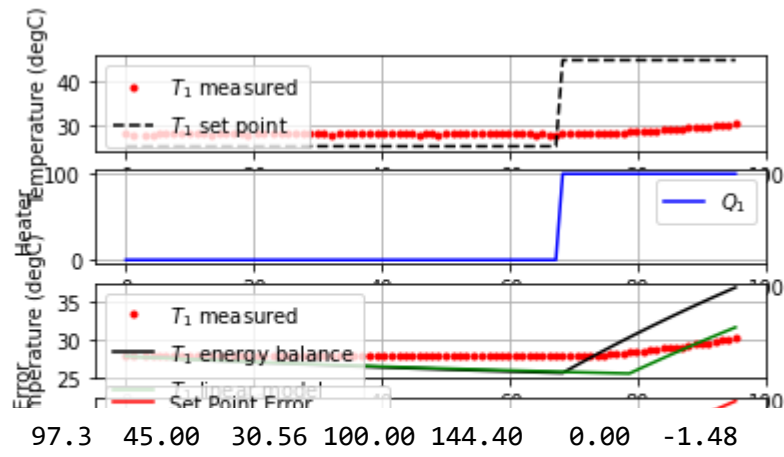


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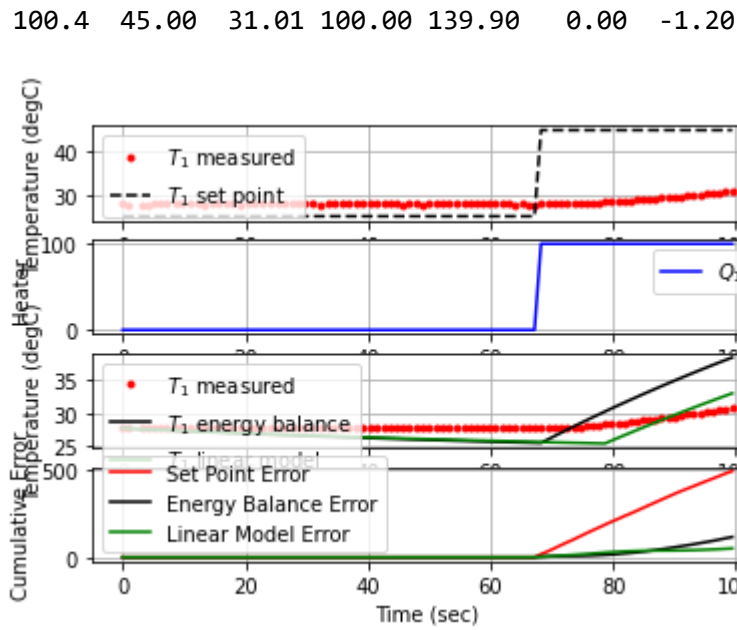
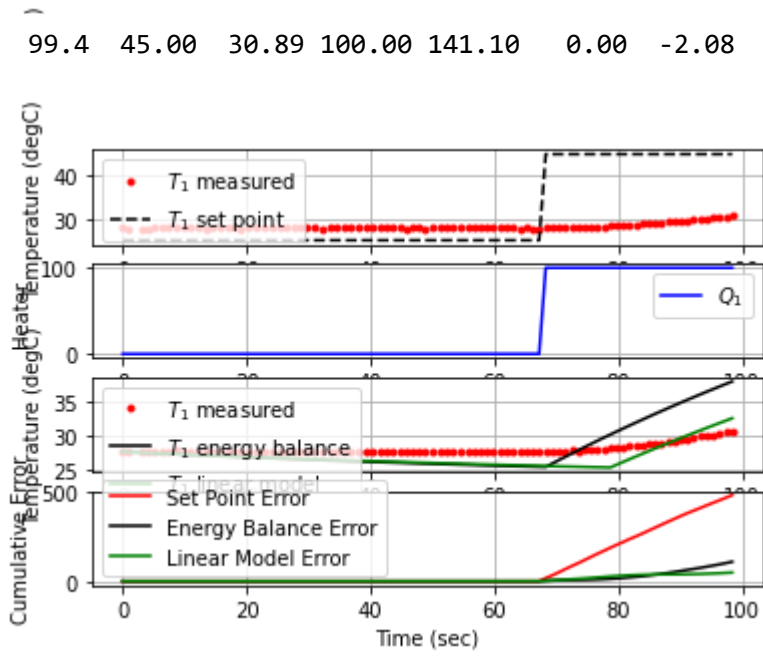


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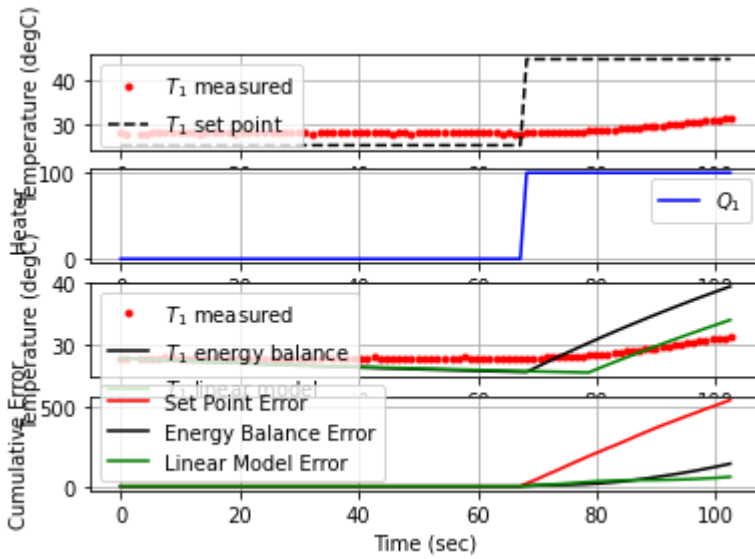
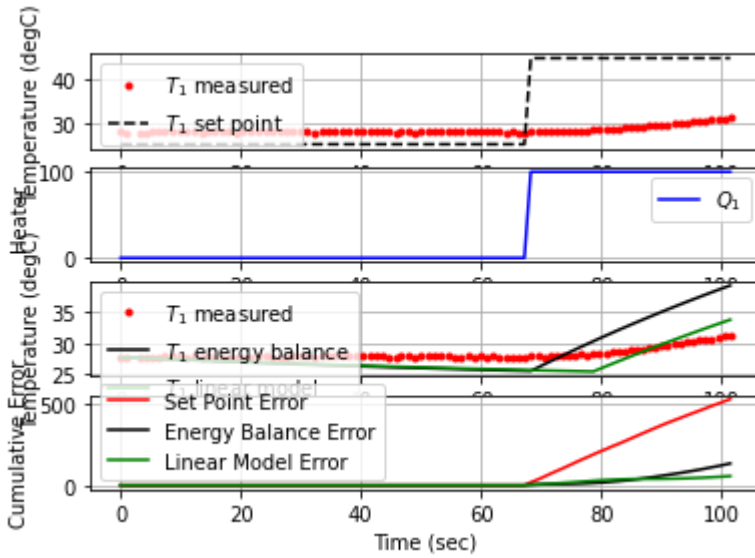
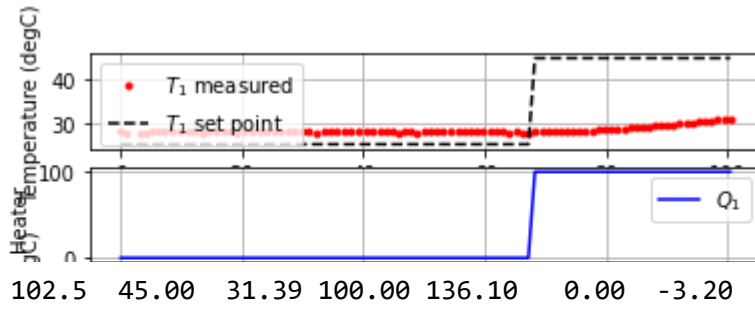


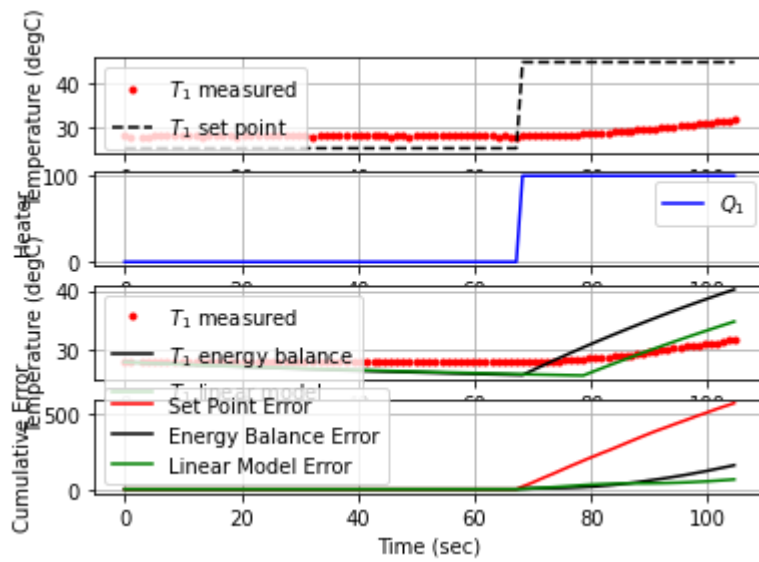
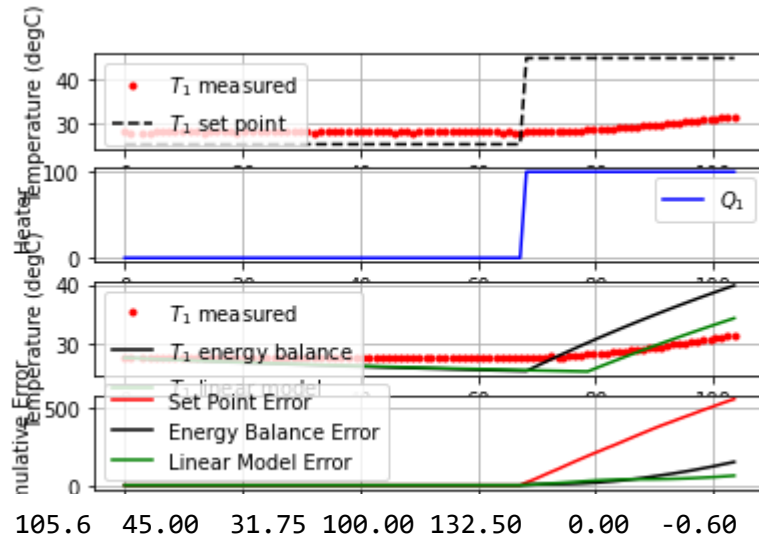


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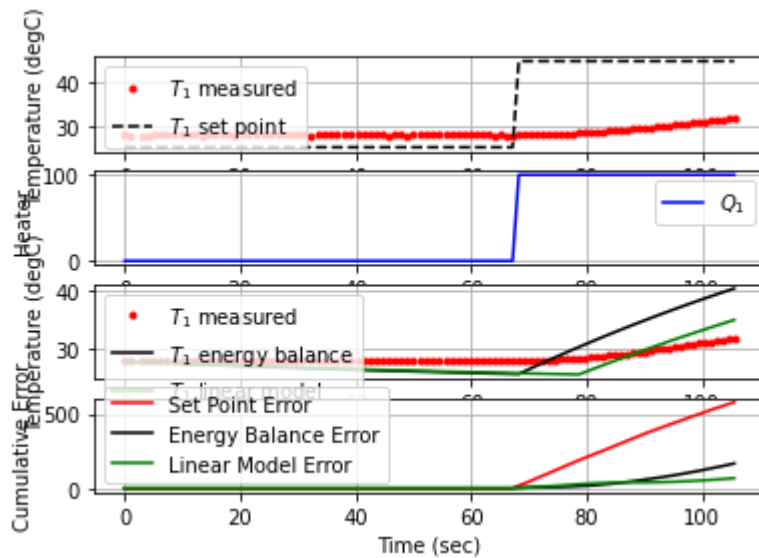


101.4 45.00 31.06 100.00 139.40 0.00 -0.50

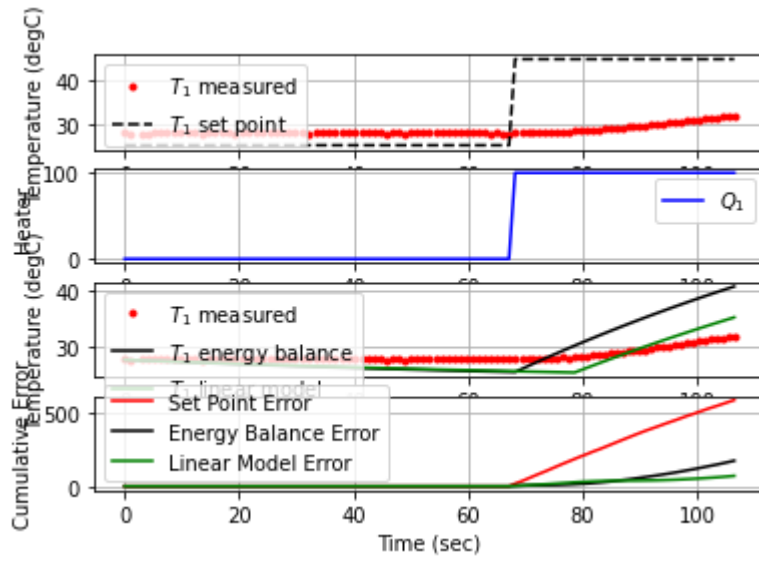




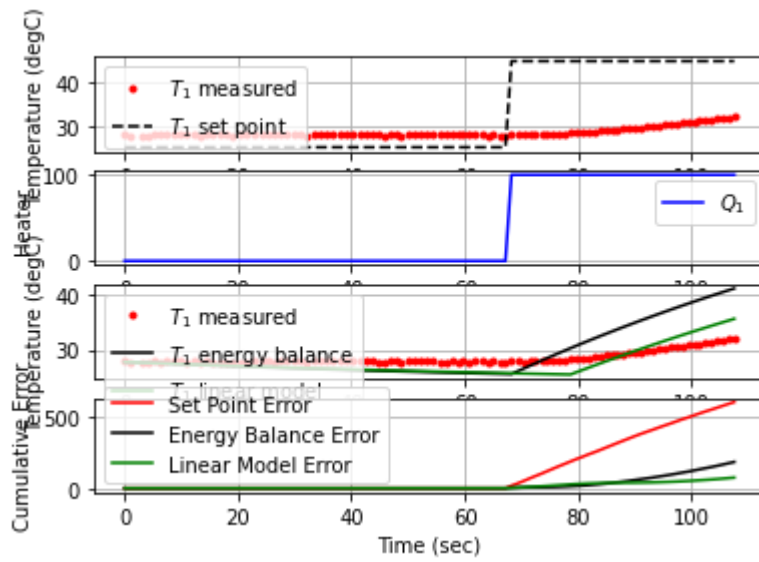
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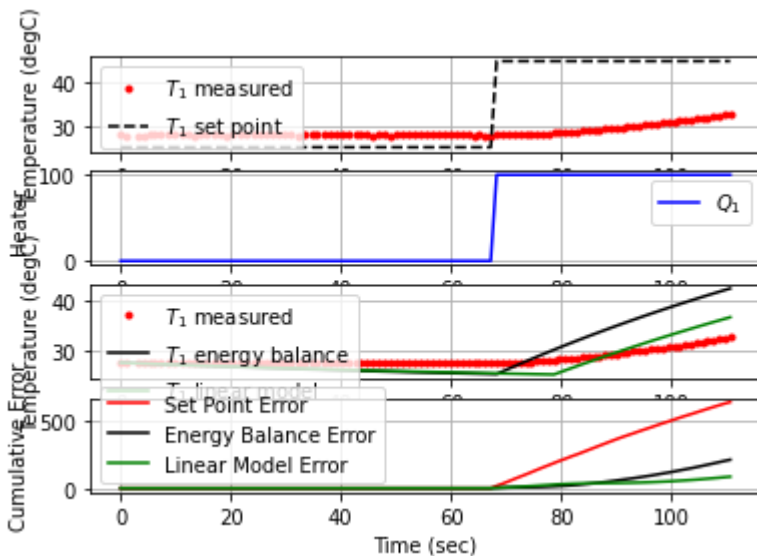
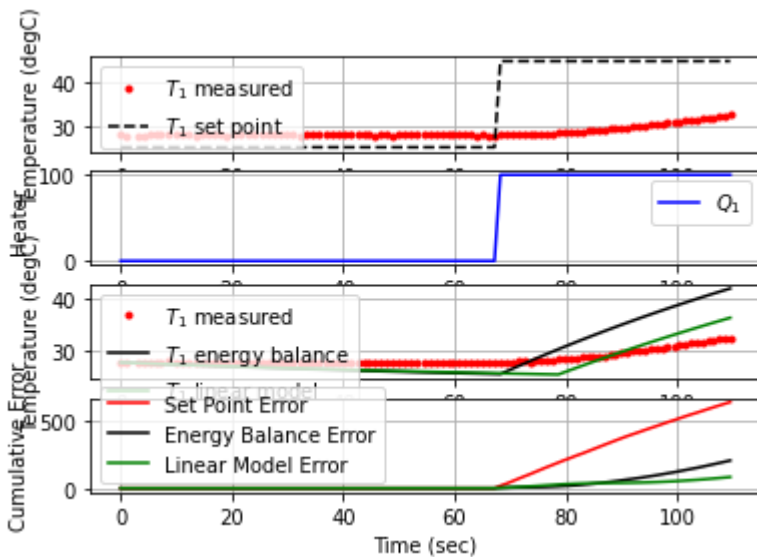
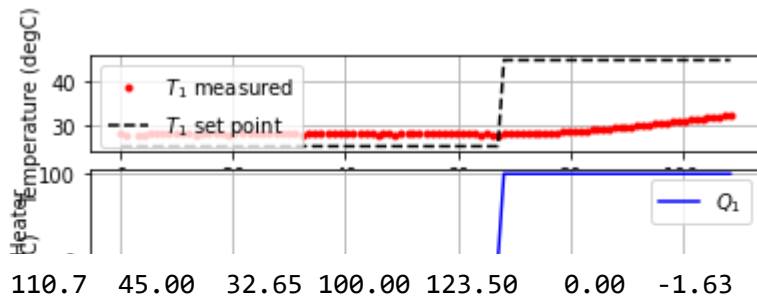
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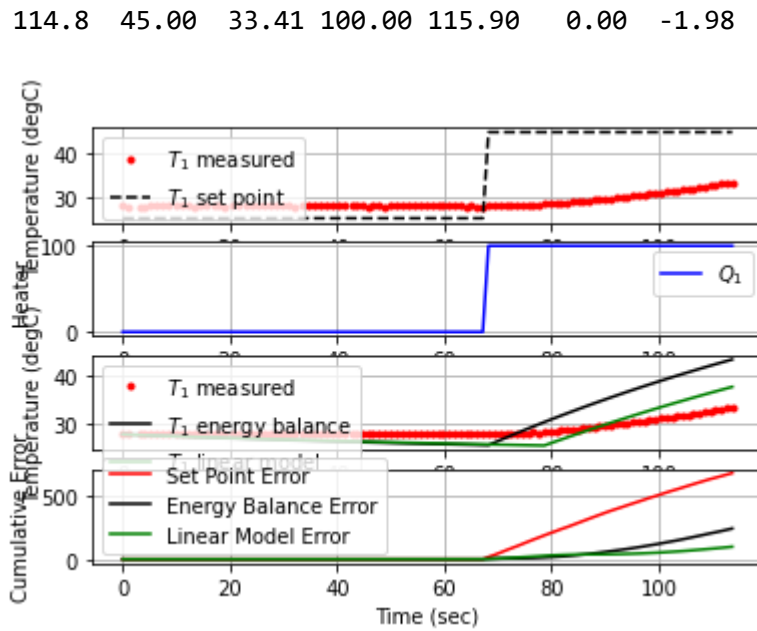
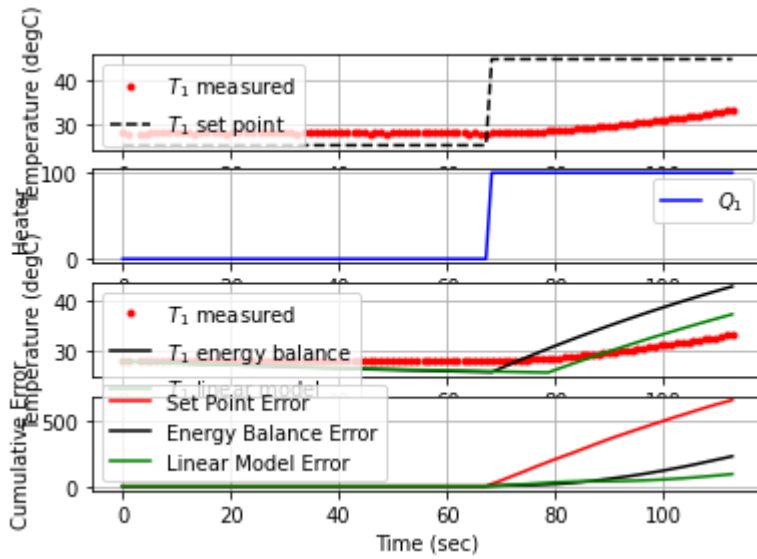
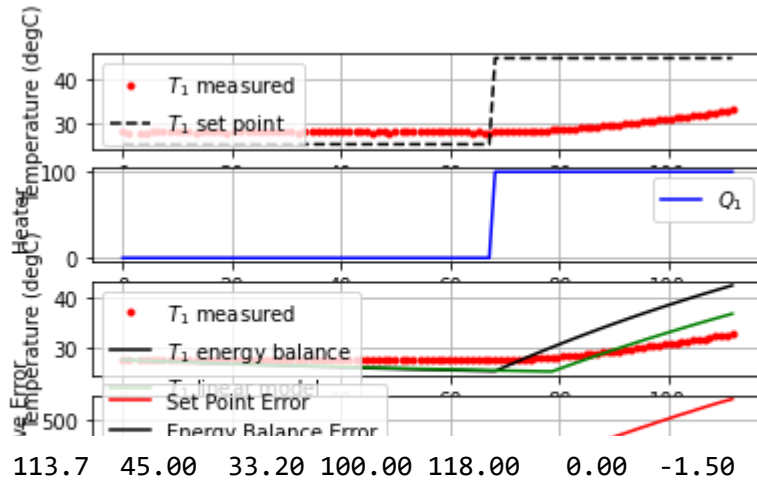


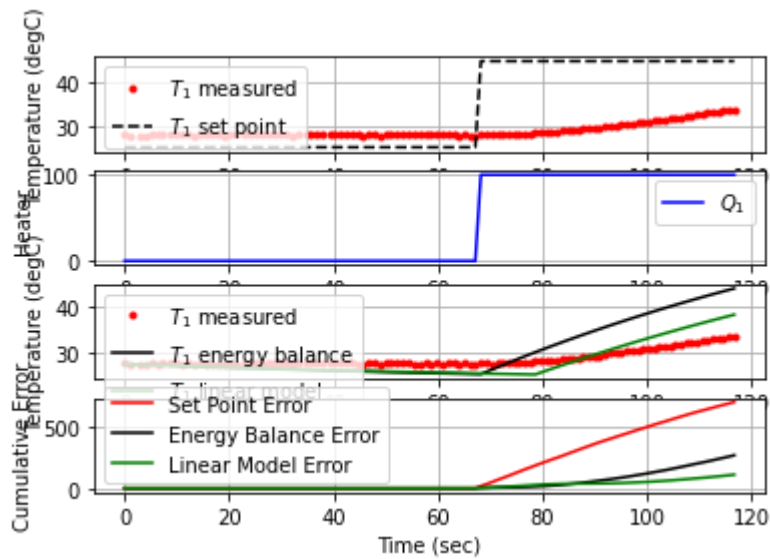
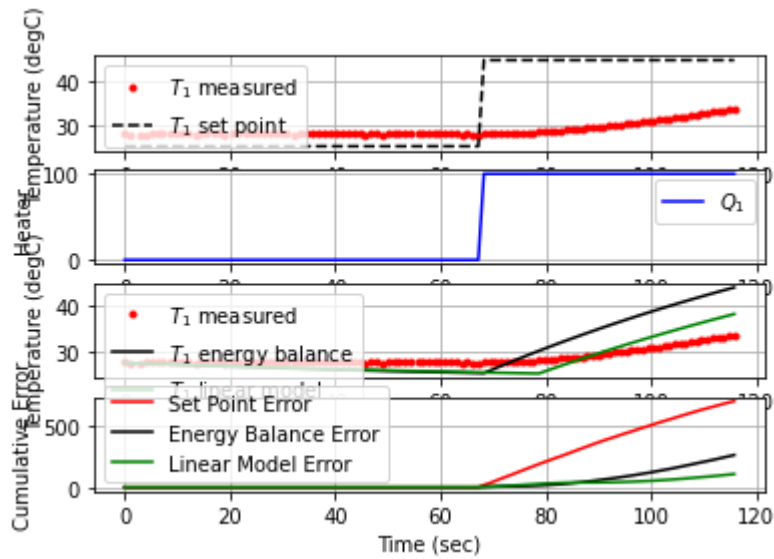
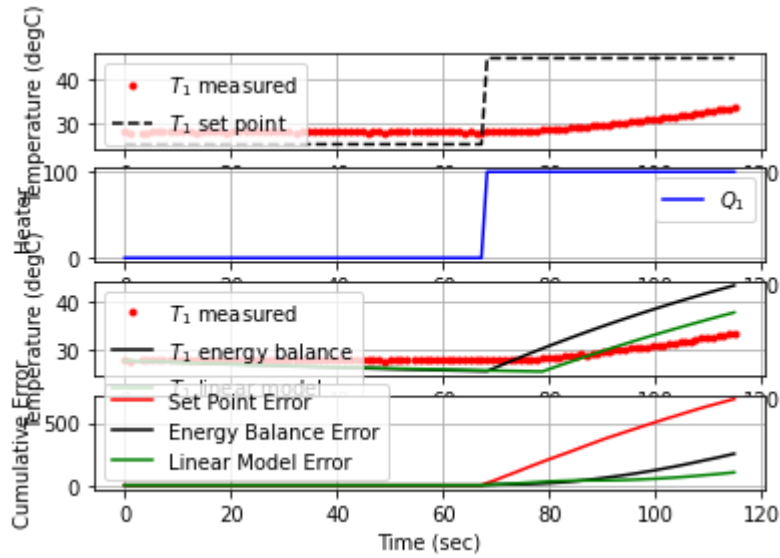
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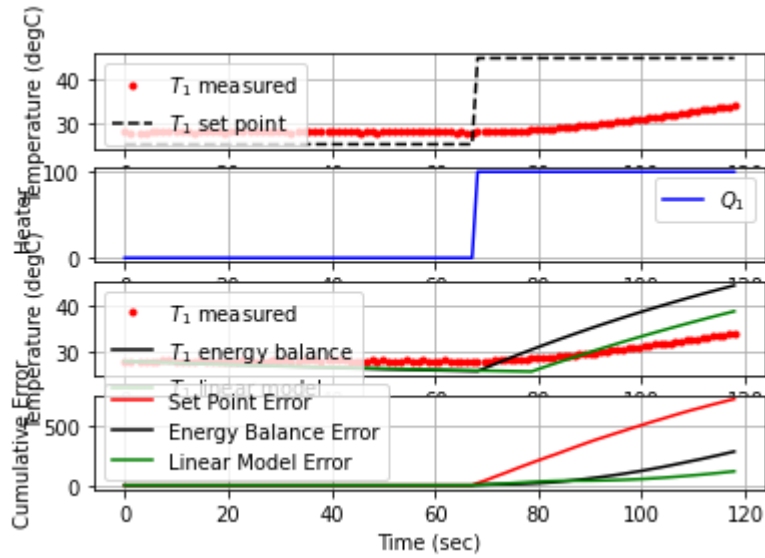
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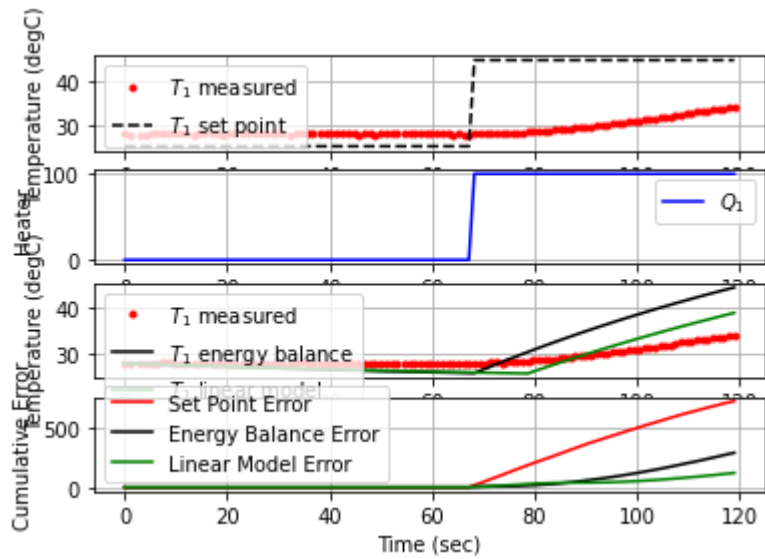




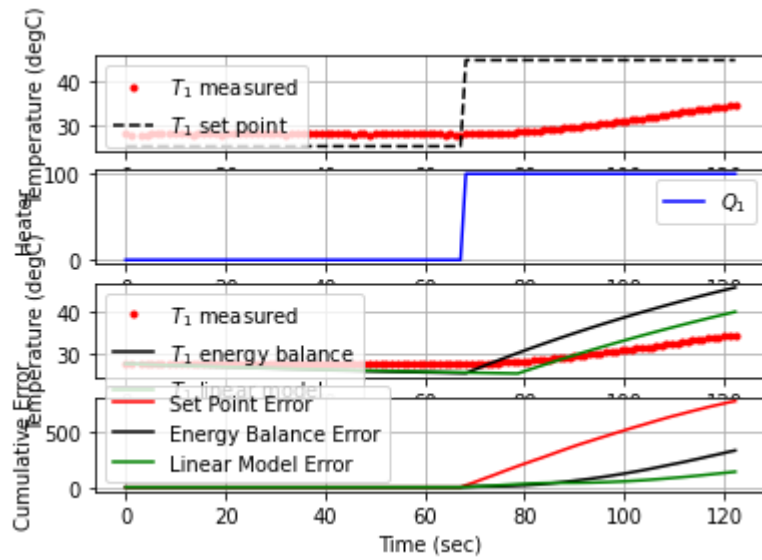
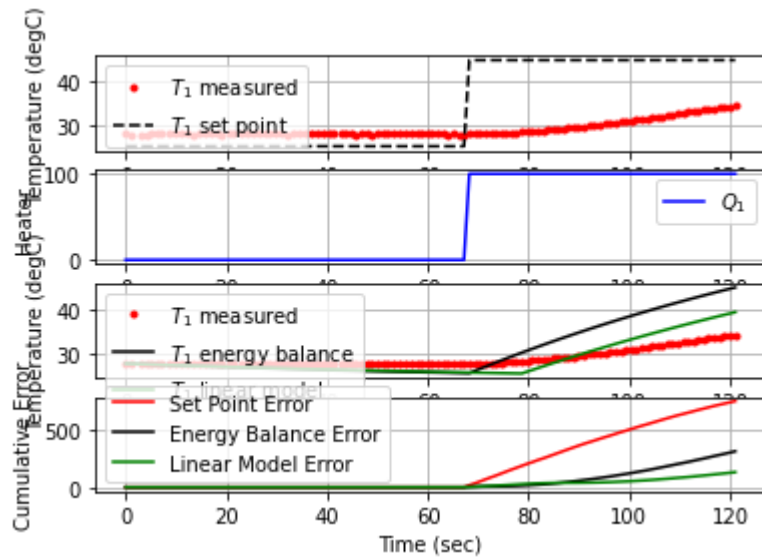
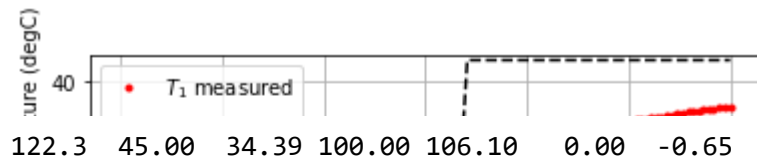
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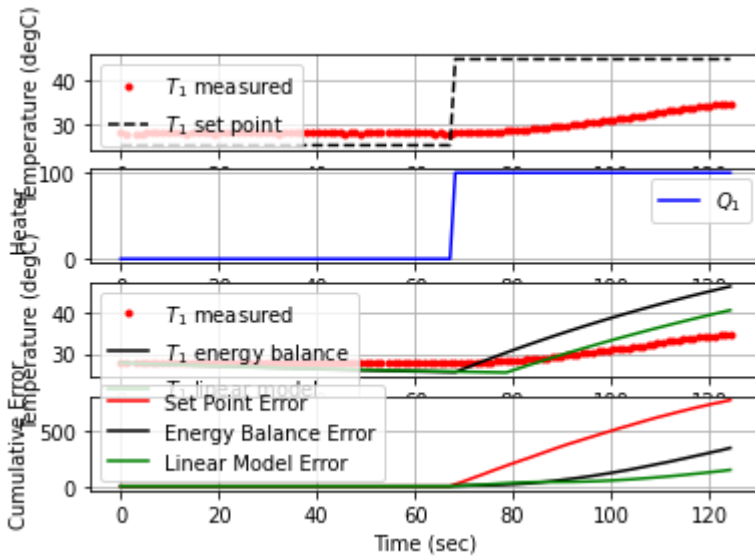
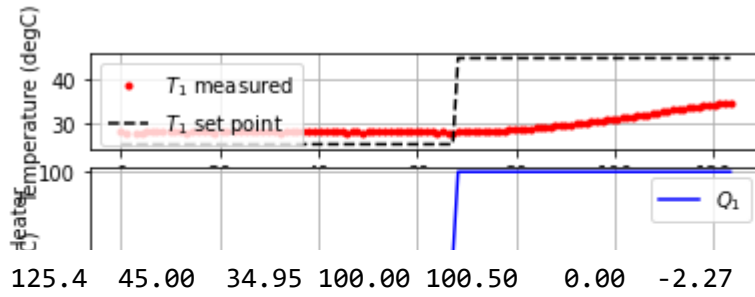


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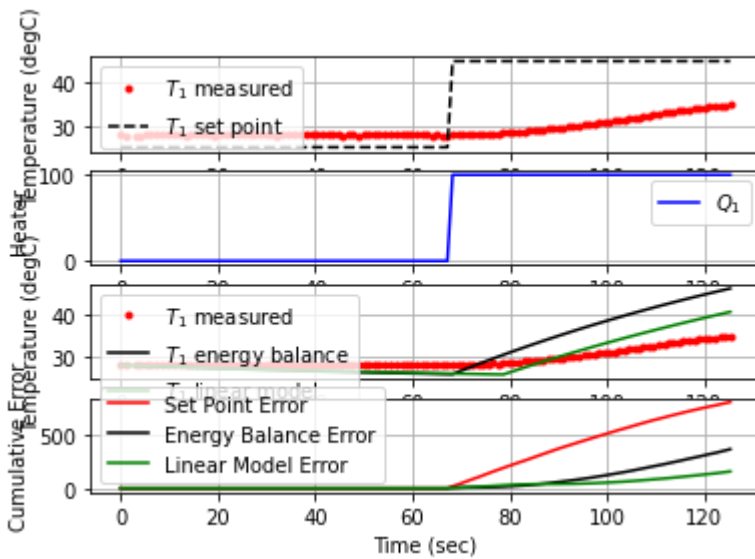


121.1 45.00 34.31 100.00 106.90 0.00 -1.46

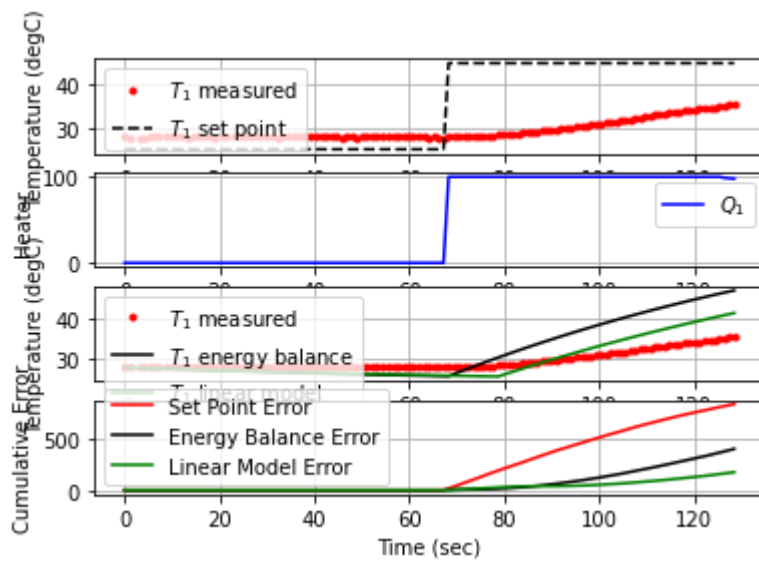
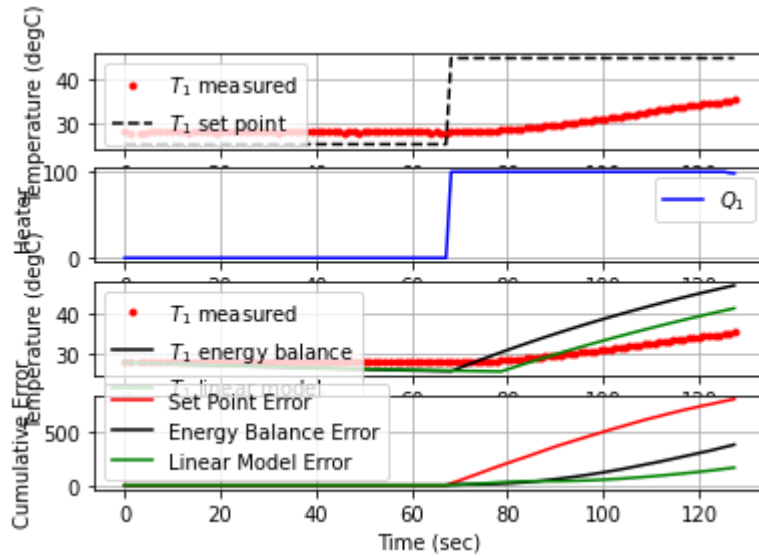
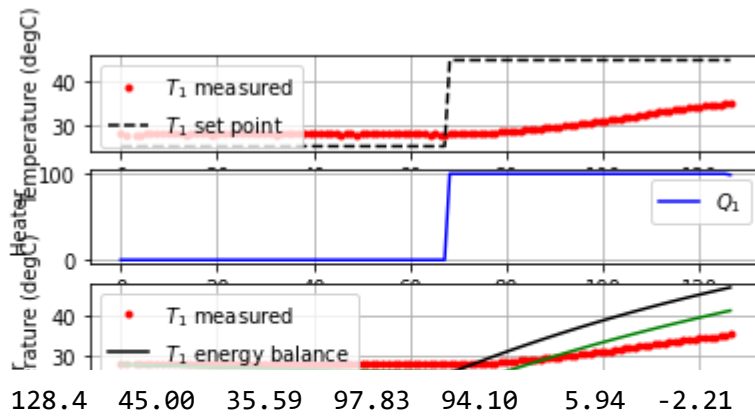


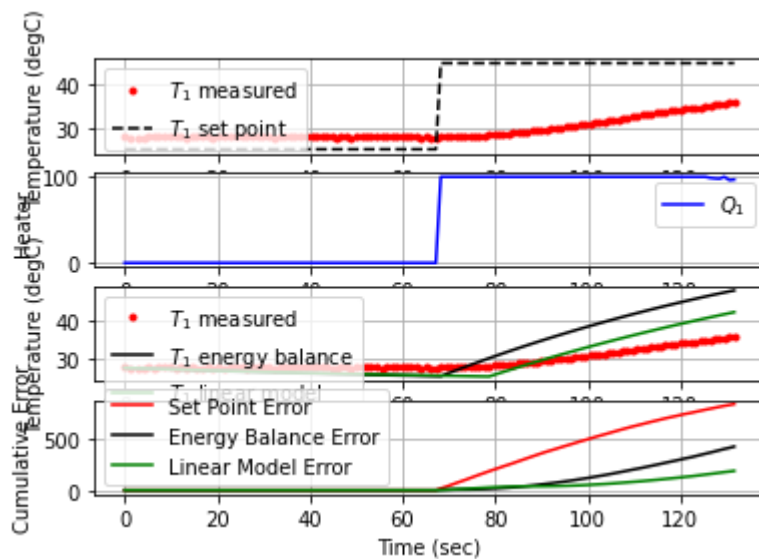
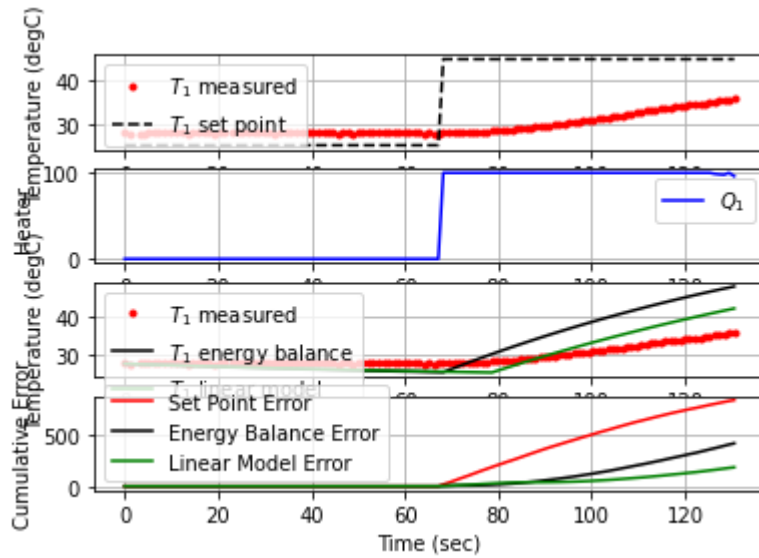
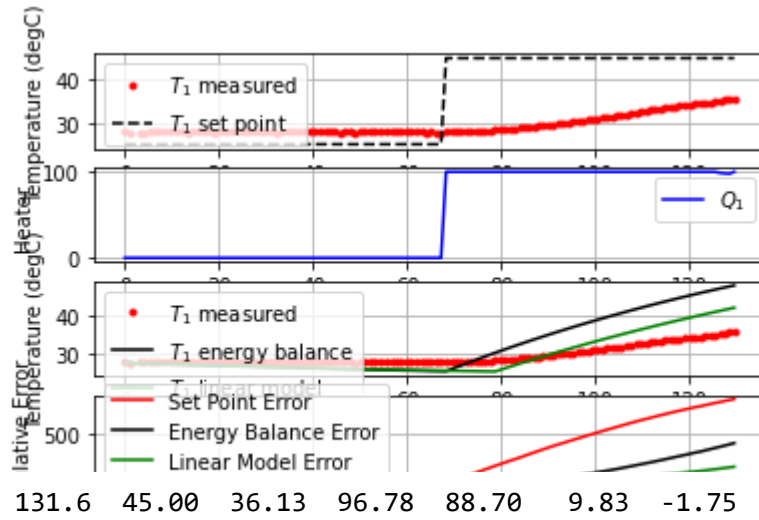


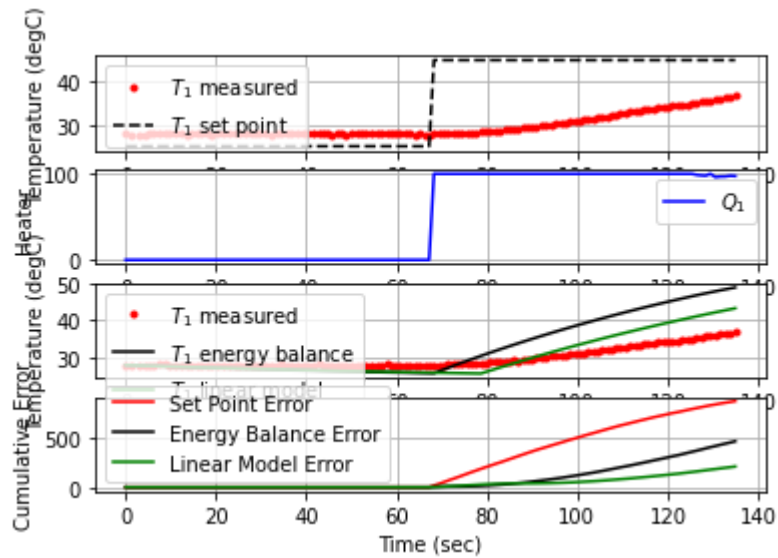
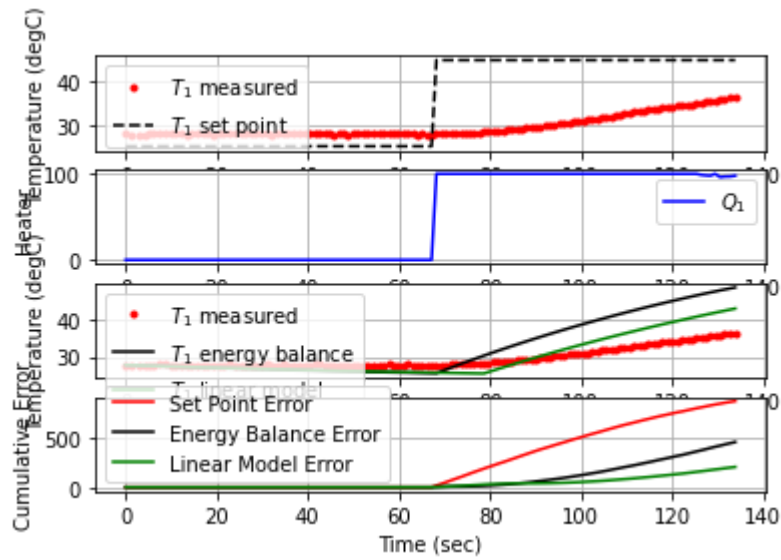
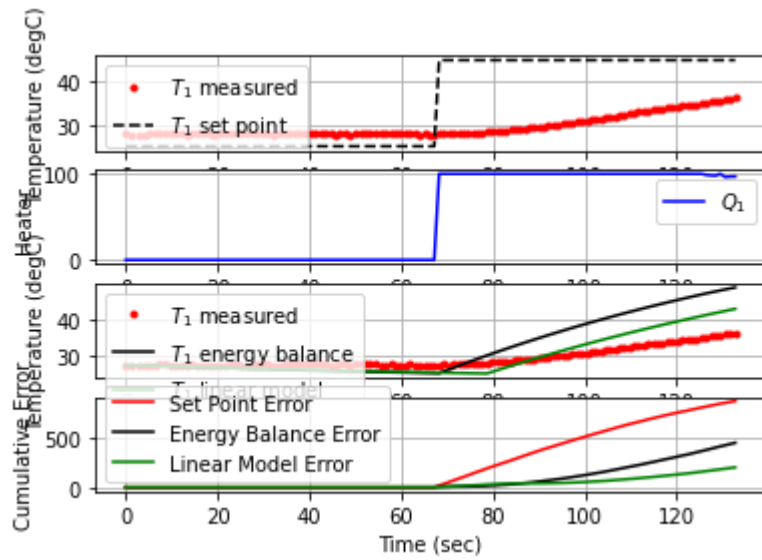
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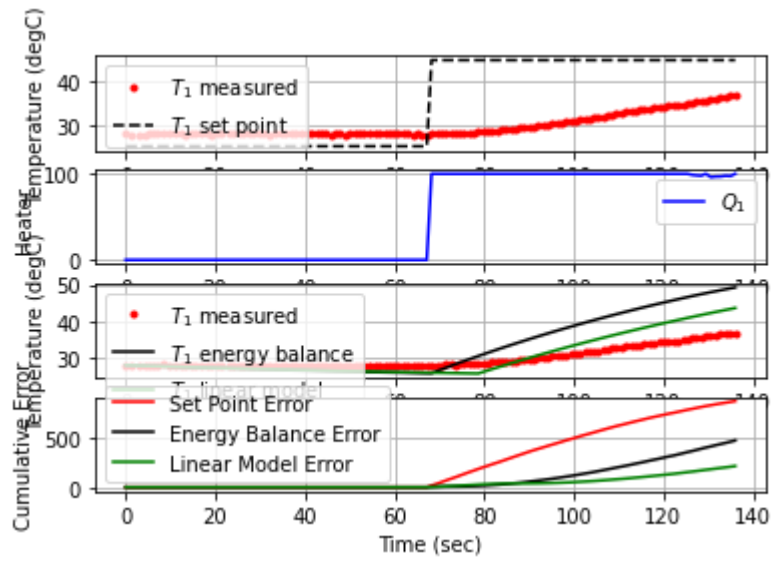
127.4 45.00 35.37 98.19 96.30 4.07 -2.17



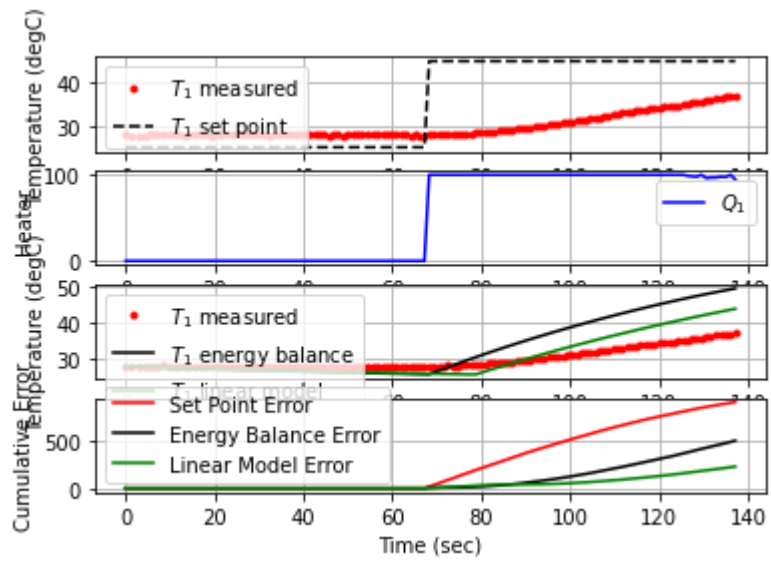




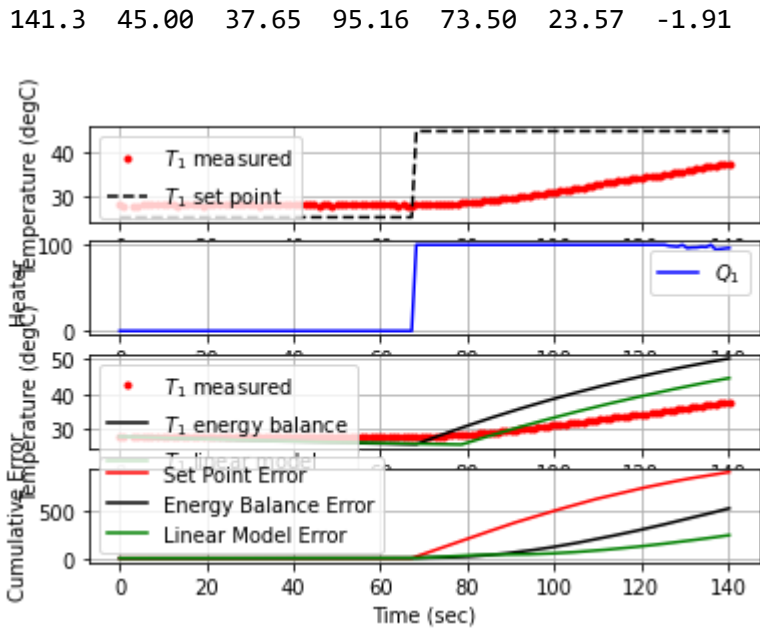
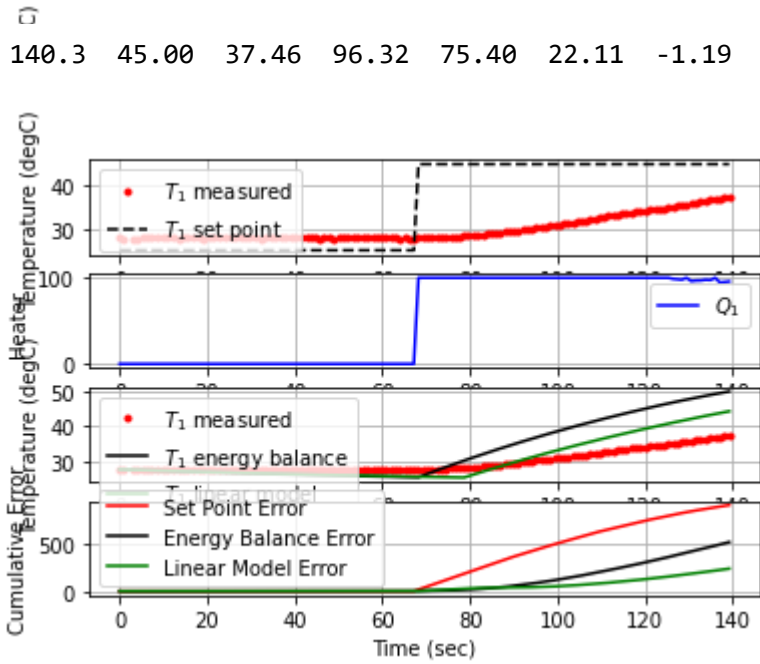
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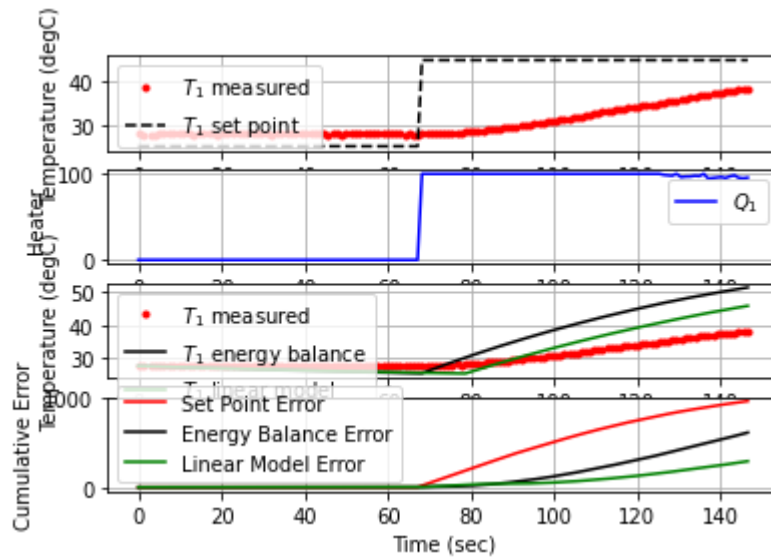
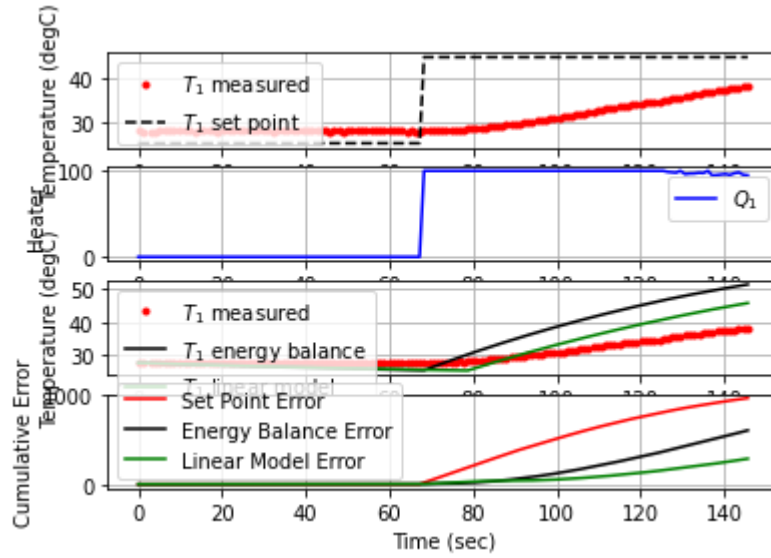
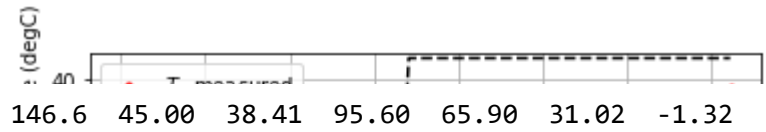
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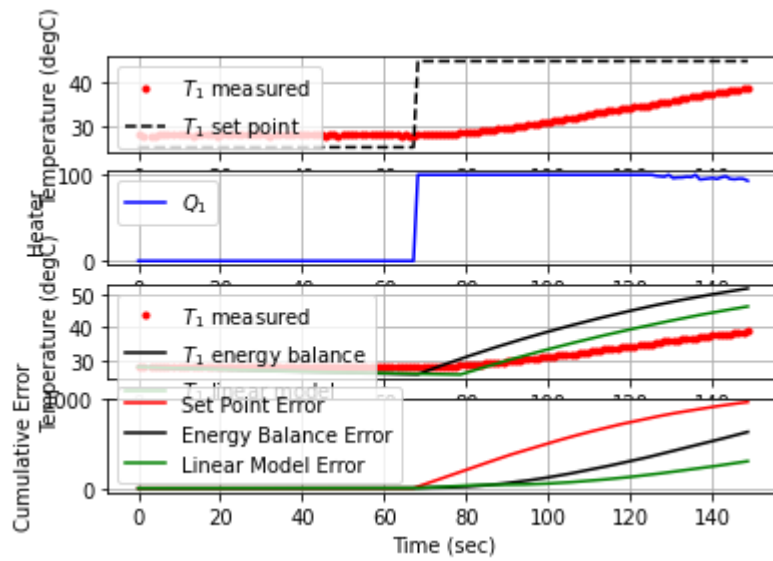
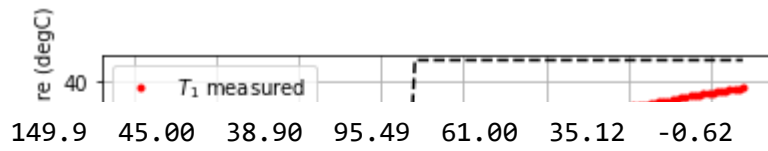


139.2 45.00 37.34 95.78 76.60 20.58 -1.41

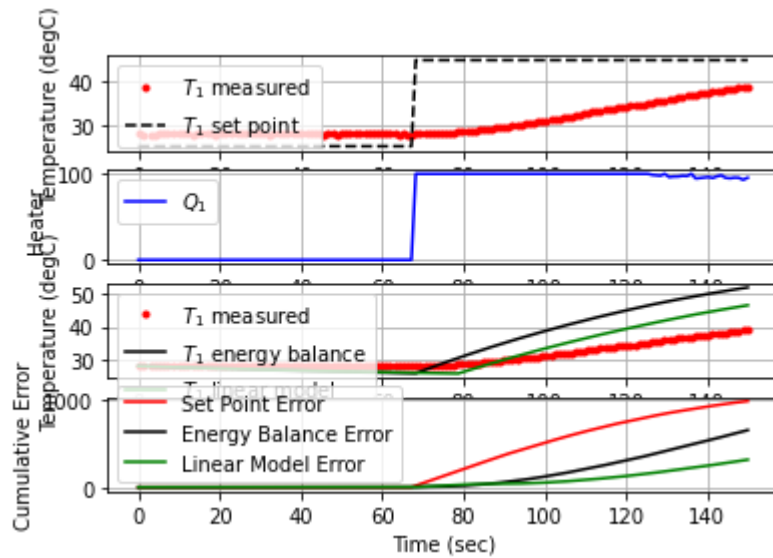


142.3 45.00 37.73 97.05 72.70 25.11 -0.76

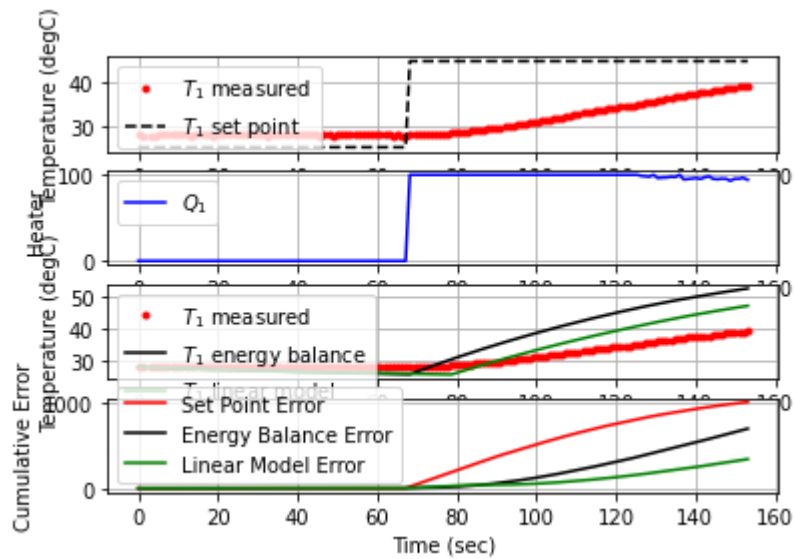
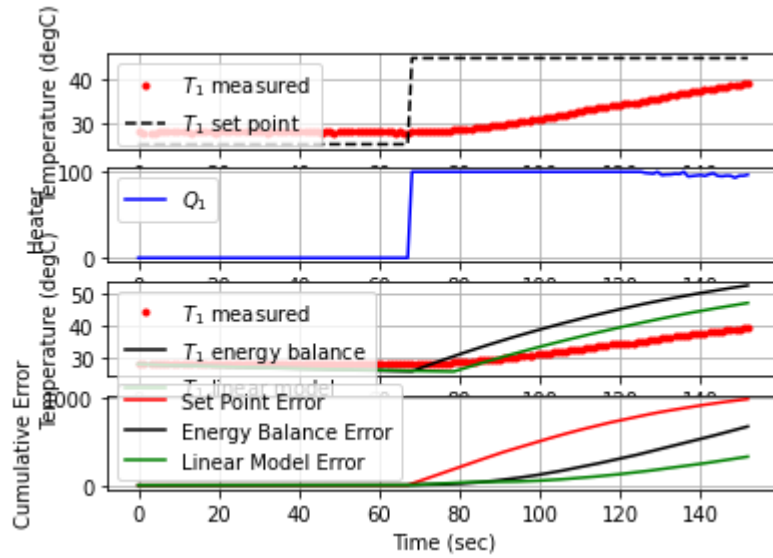
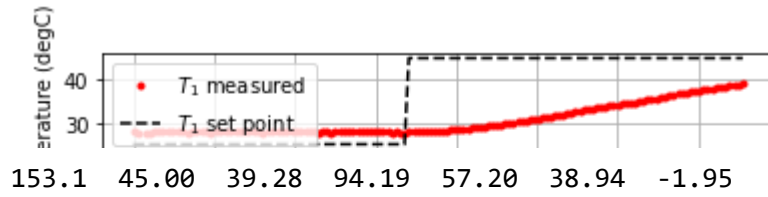


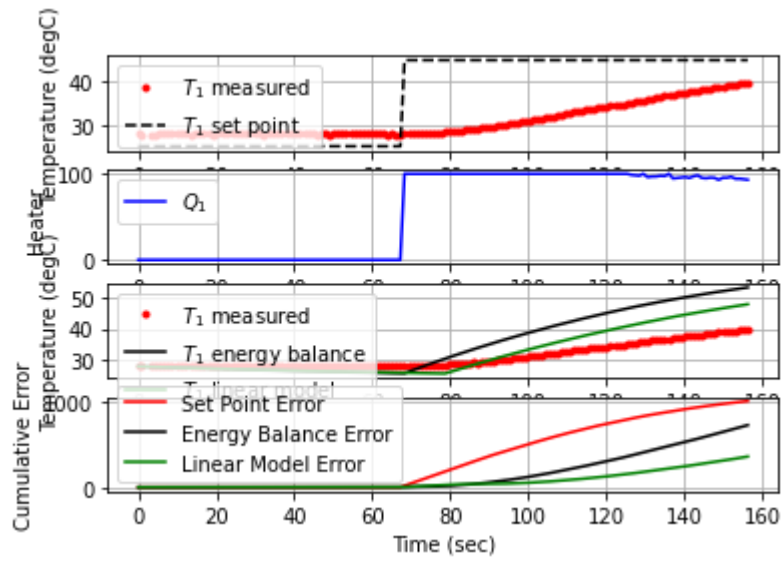
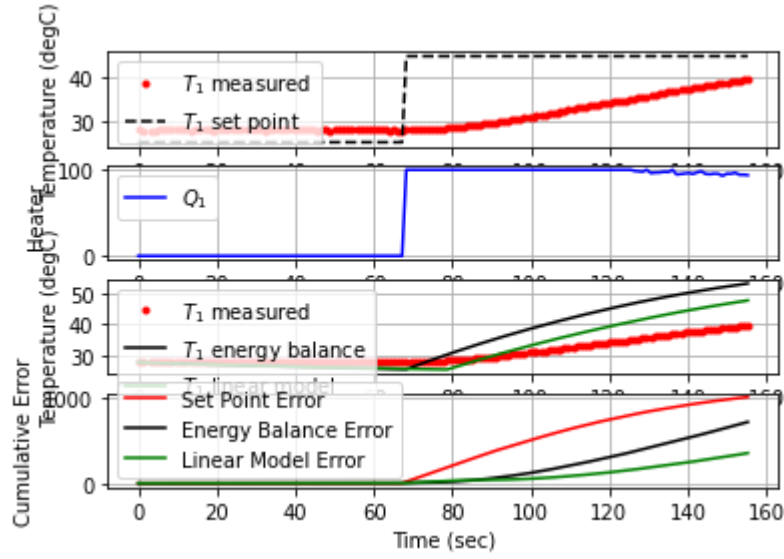
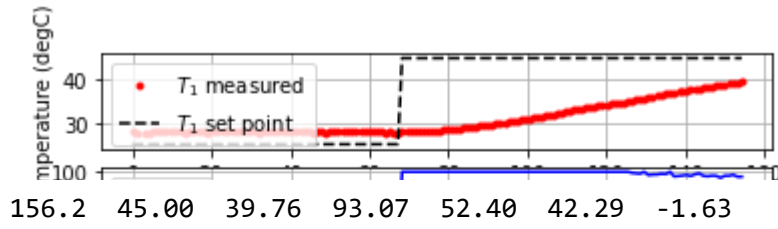


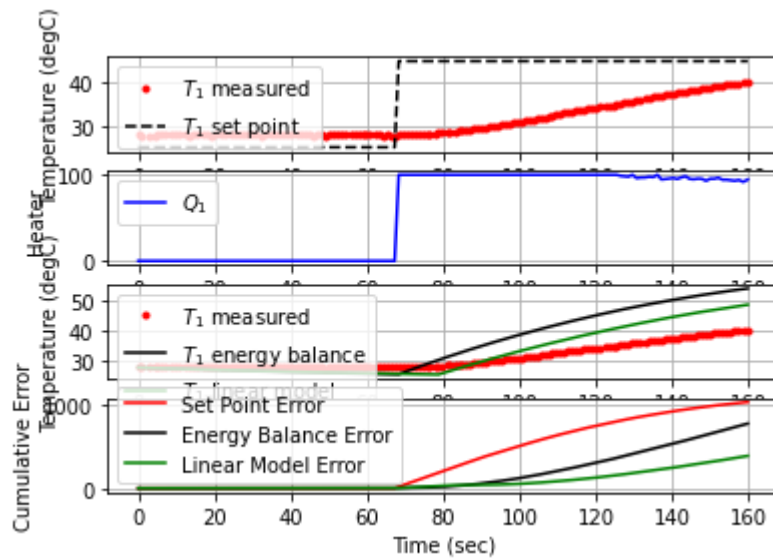
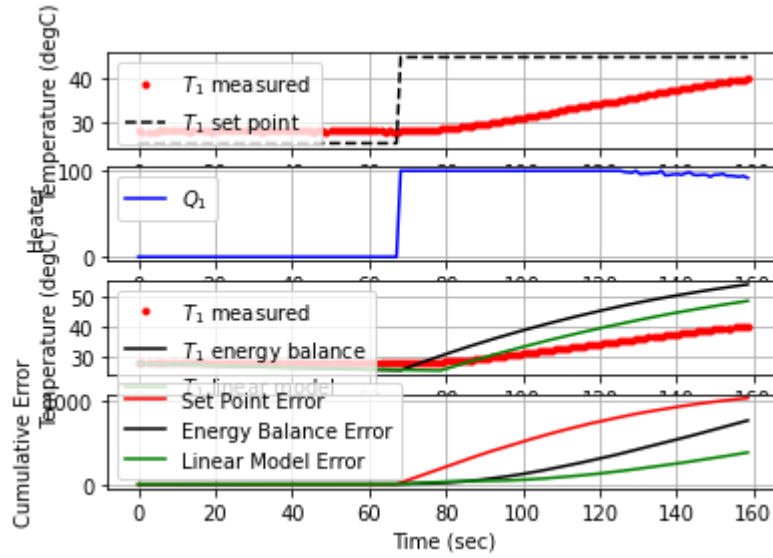
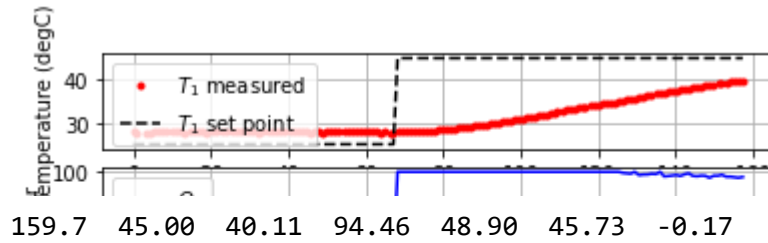
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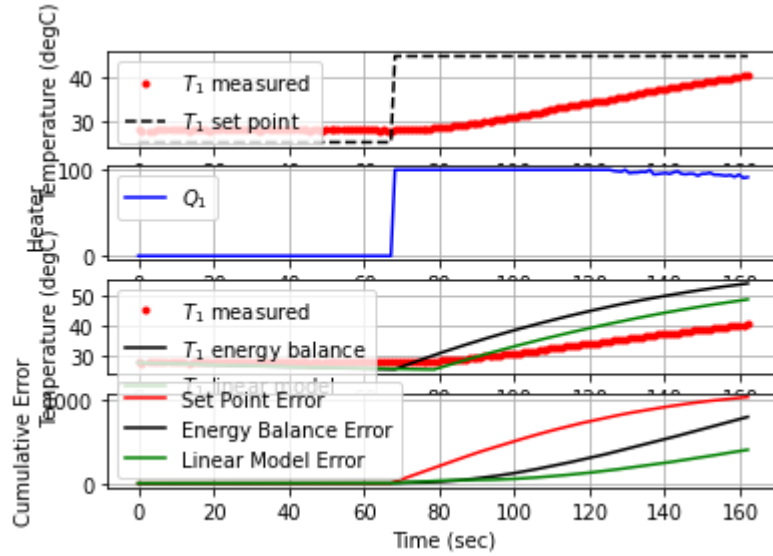
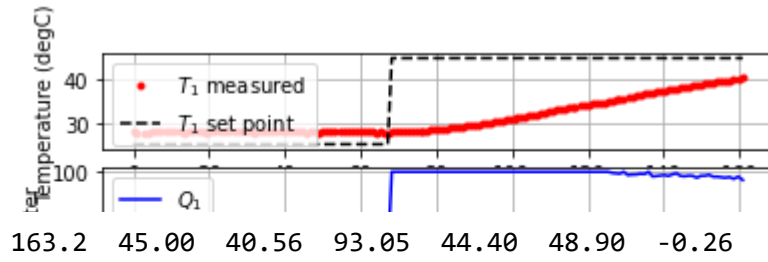


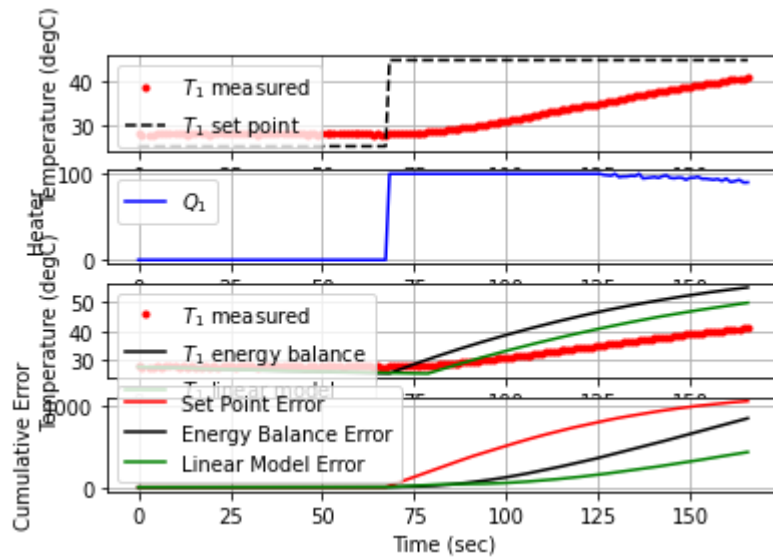
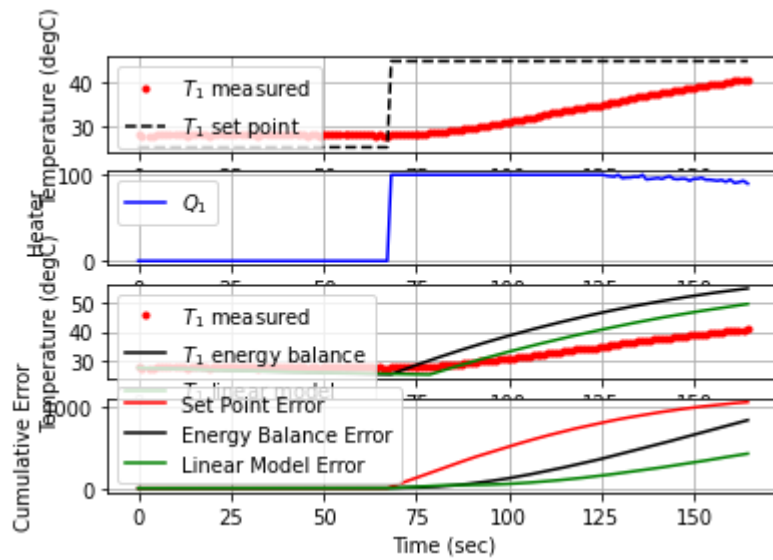
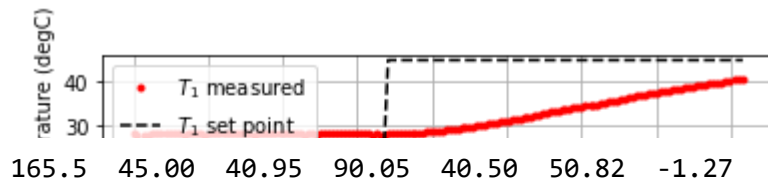
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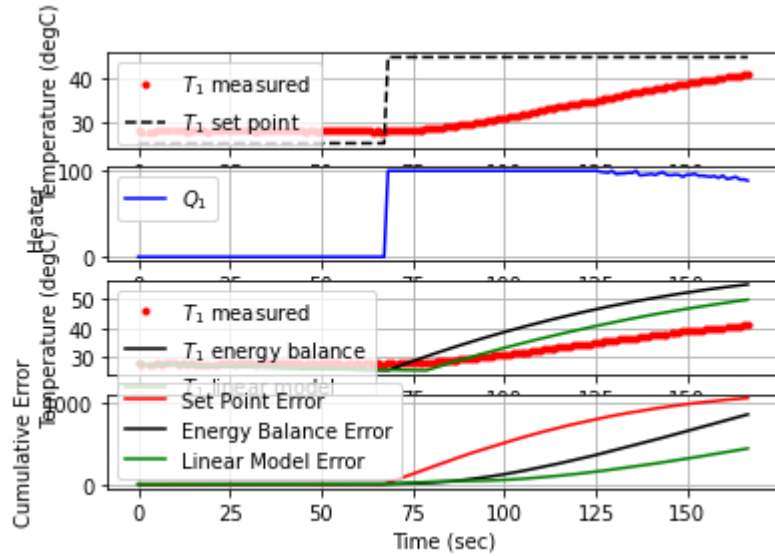




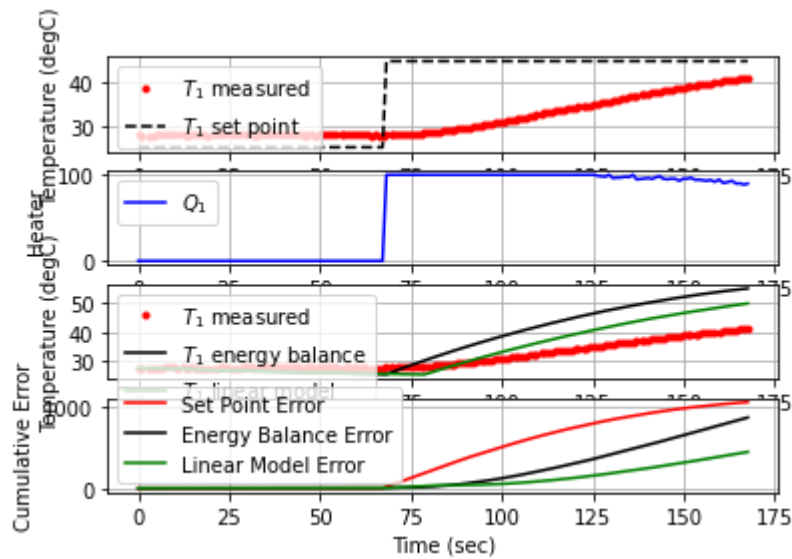




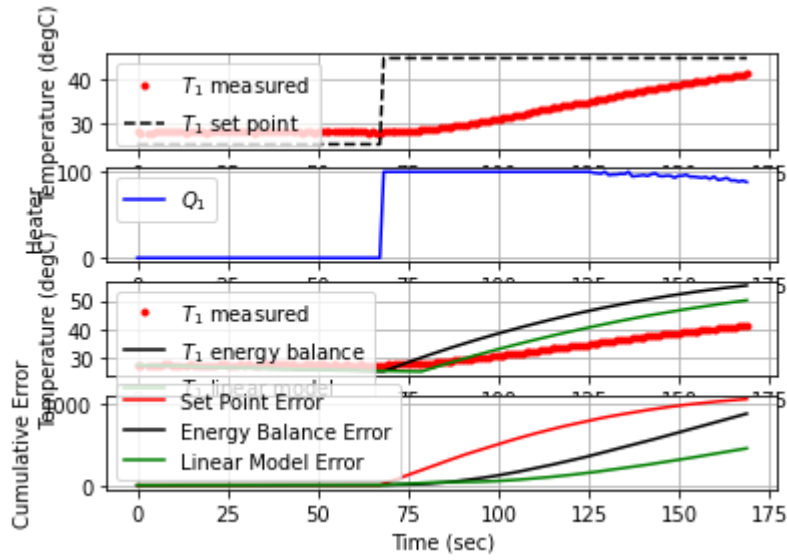
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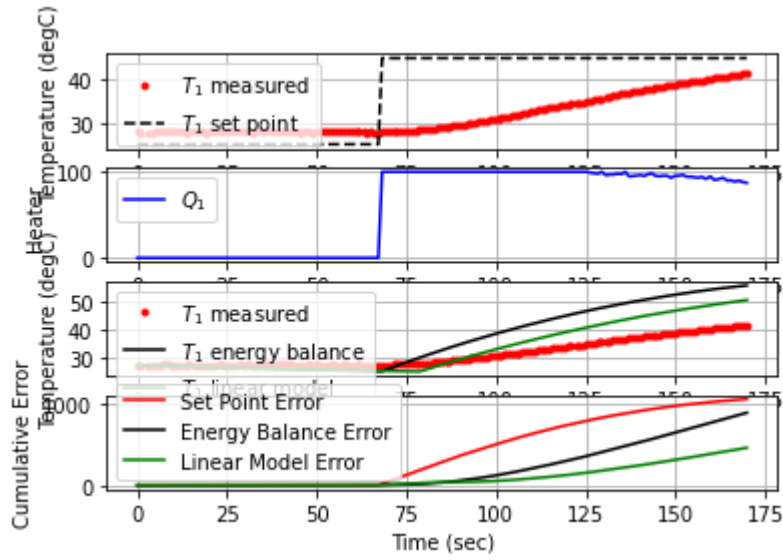
168.8 45.00 41.37 88.08 36.30 53.25 -1.47



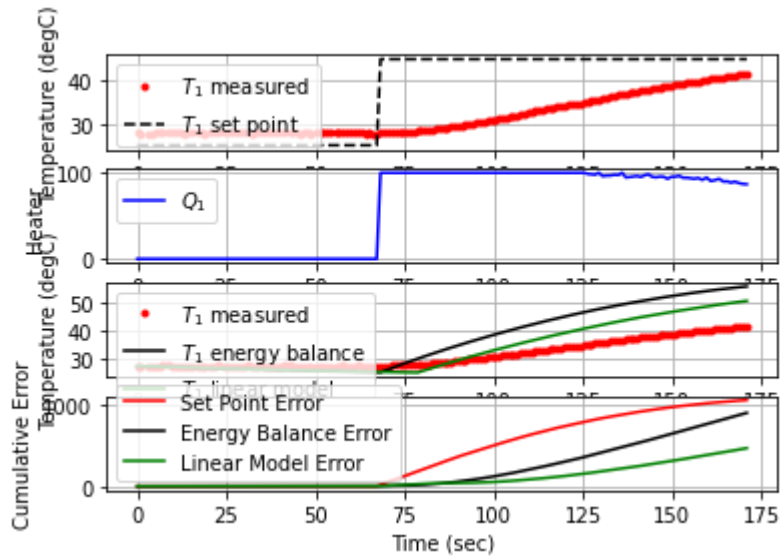
169.9 45.00 41.54 87.05 34.60 54.00 -1.56



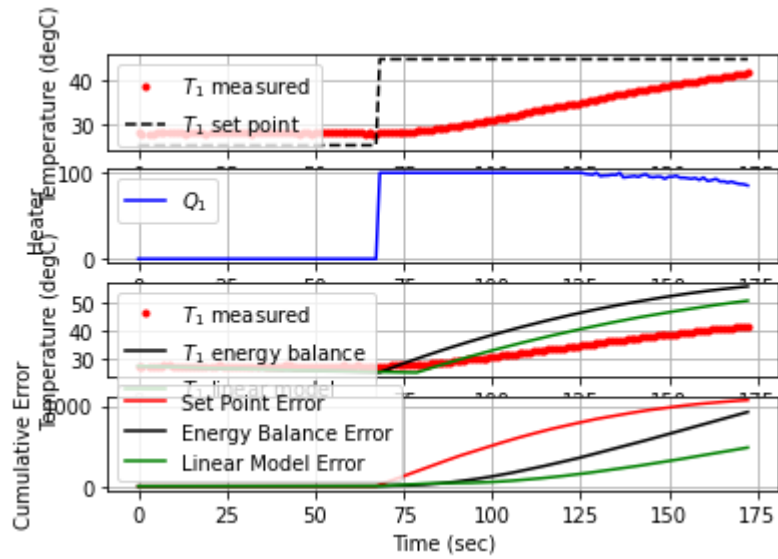
171.0 45.00 41.68 86.70 33.20 54.75 -1.25



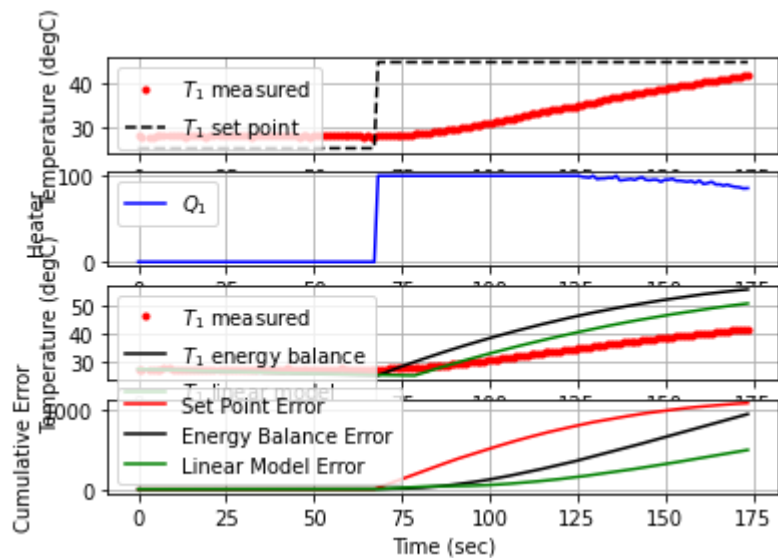
172.2 45.00 41.87 85.27 31.30 55.52 -1.54



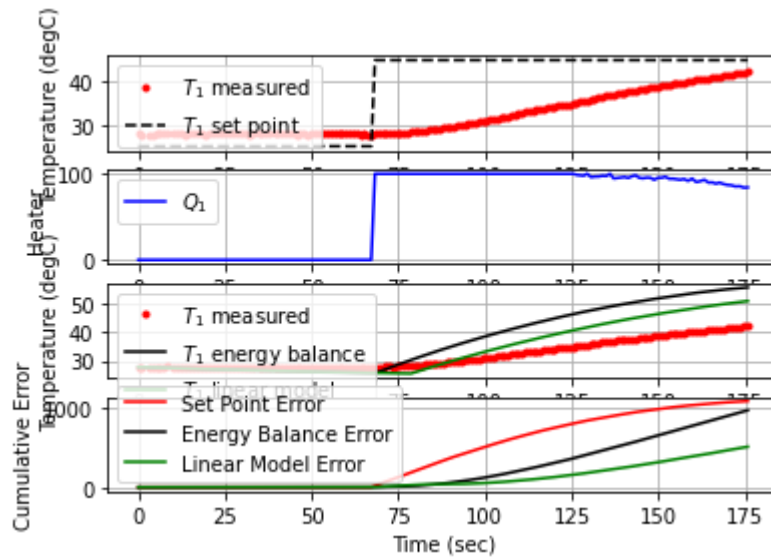
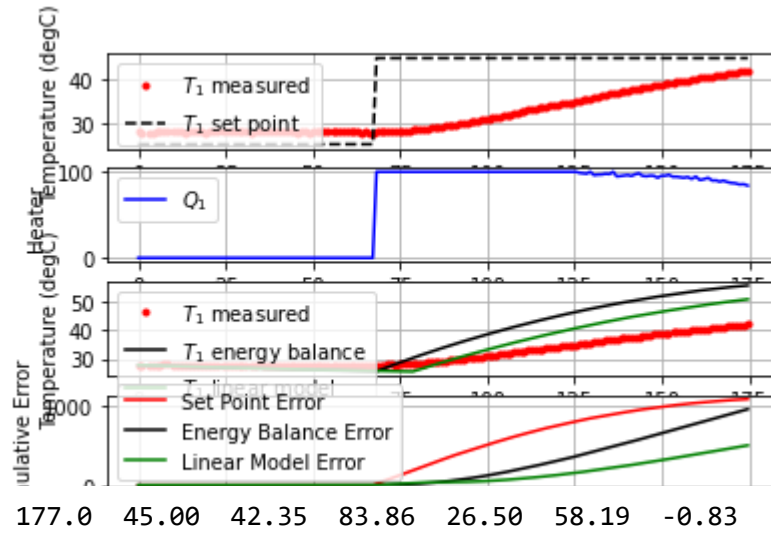
173.5 45.00 41.98 85.59 30.70 56.27 -0.88



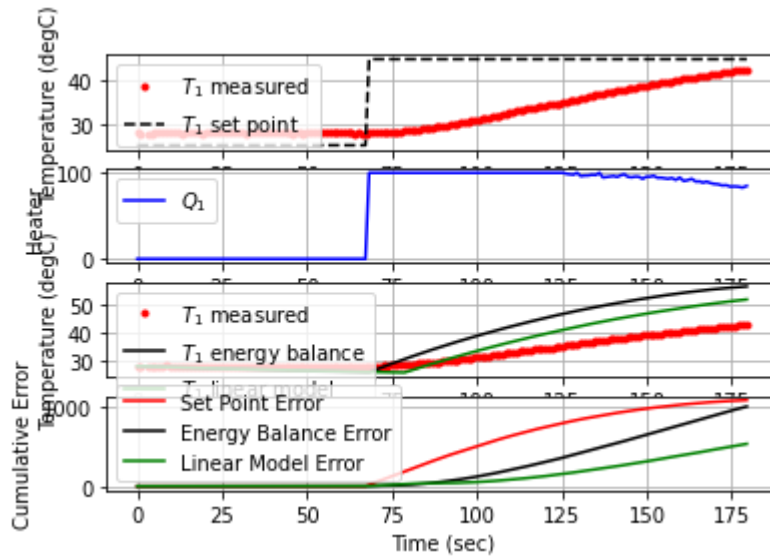
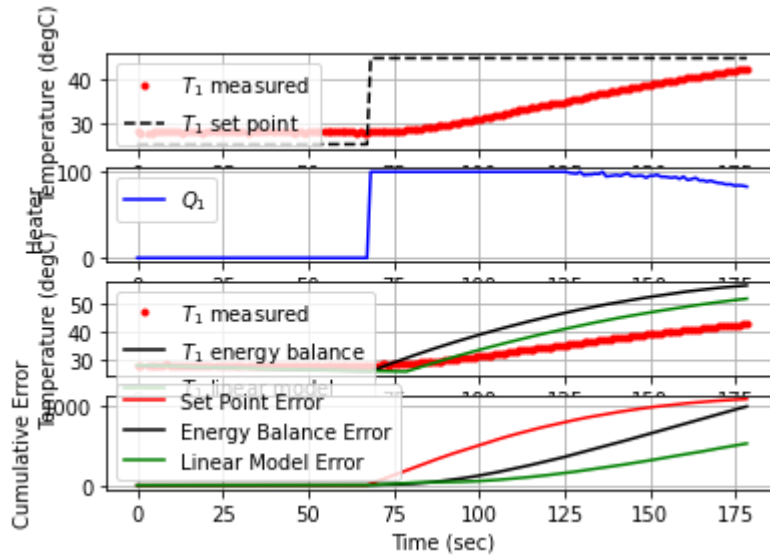
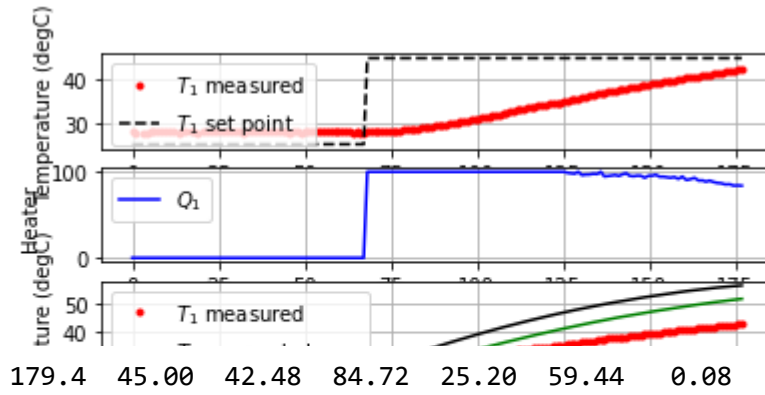
174.6 45.00 42.15 83.90 28.50 56.91 -1.51



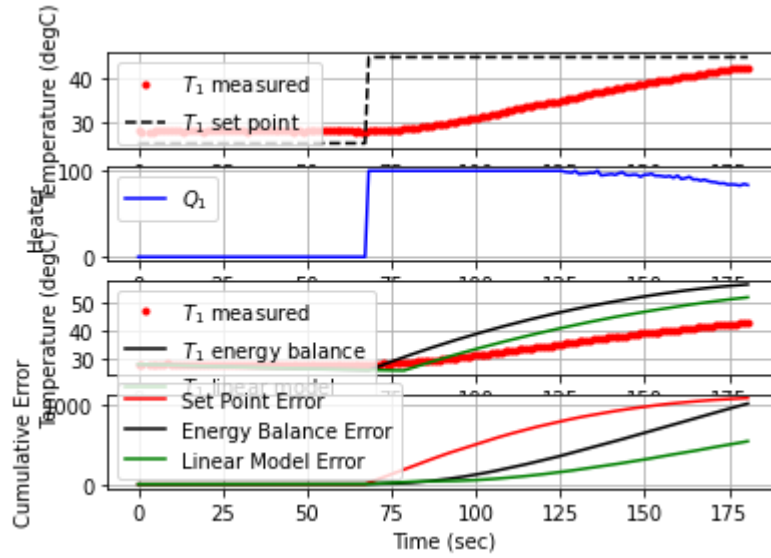
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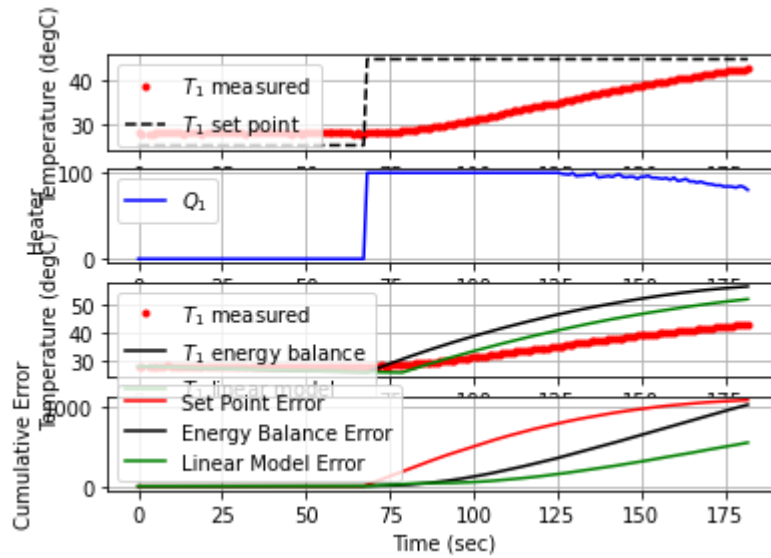
178.2 45.00 42.49 82.79 25.10 58.81 -1.12



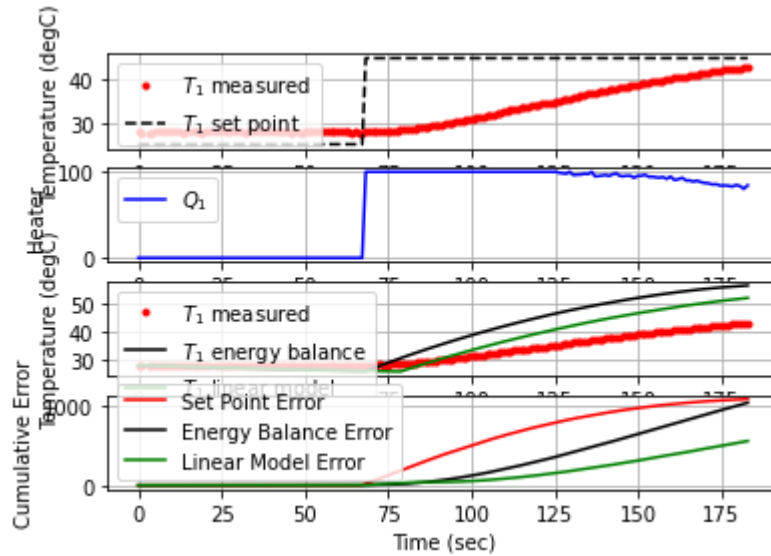
181.7 45.00 42.82 80.14 21.80 60.48 -2.14



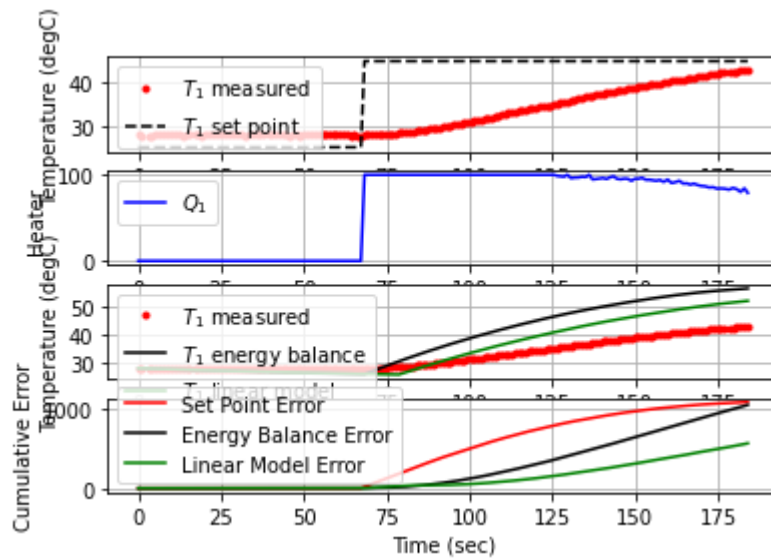
182.9 45.00 42.74 84.29 22.60 61.00 0.68



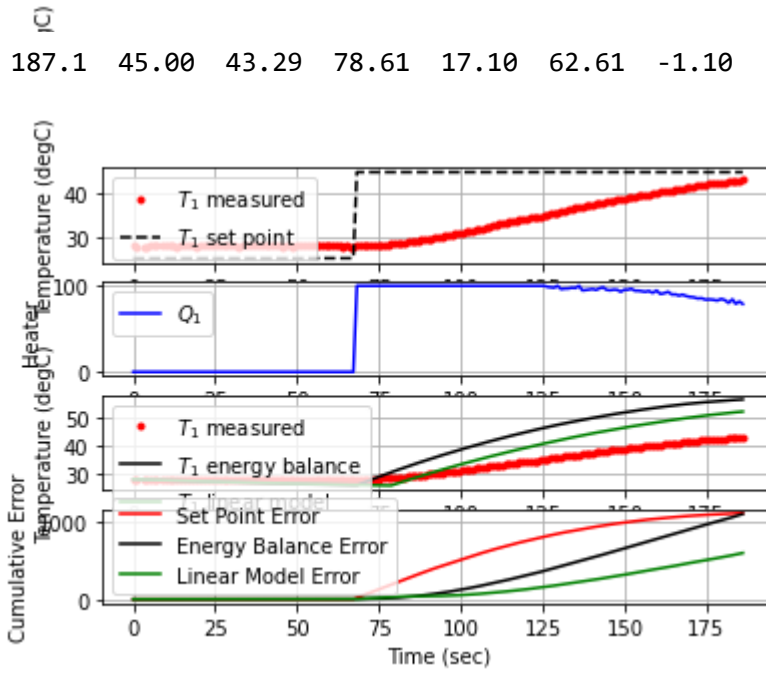
183.9 45.00 42.99 79.05 20.10 61.41 -2.47



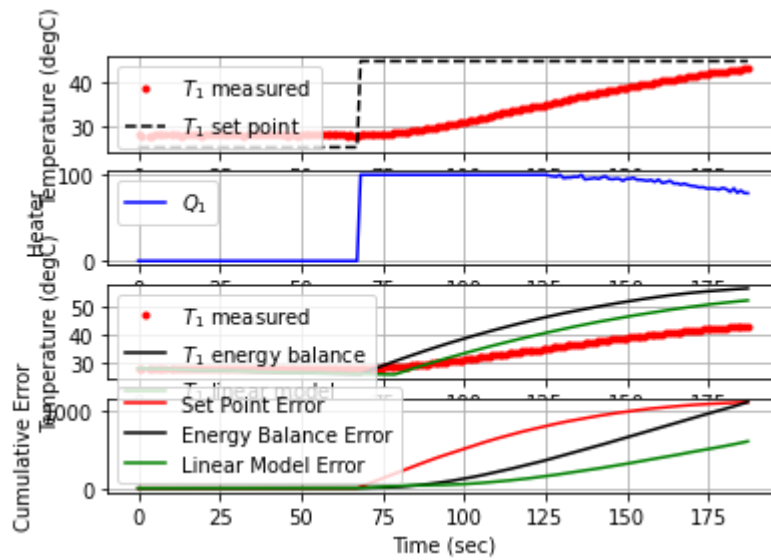
185.0 45.00 43.00 81.77 20.00 61.86 -0.09



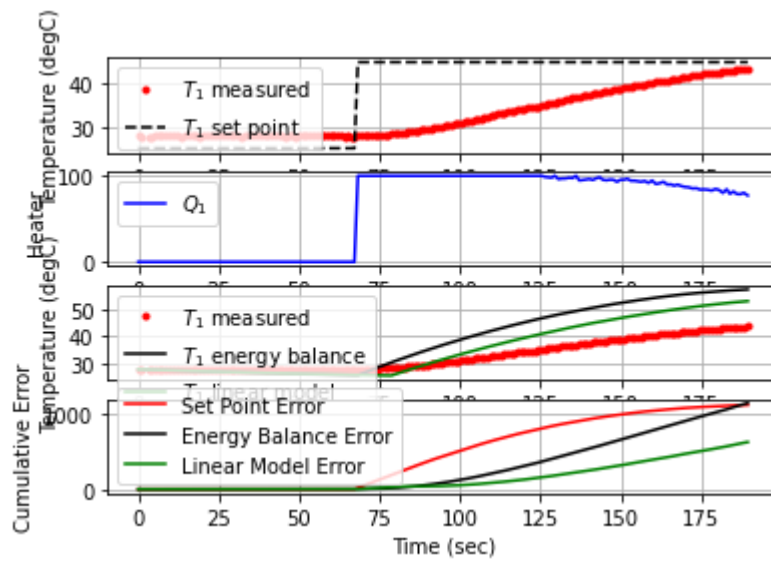
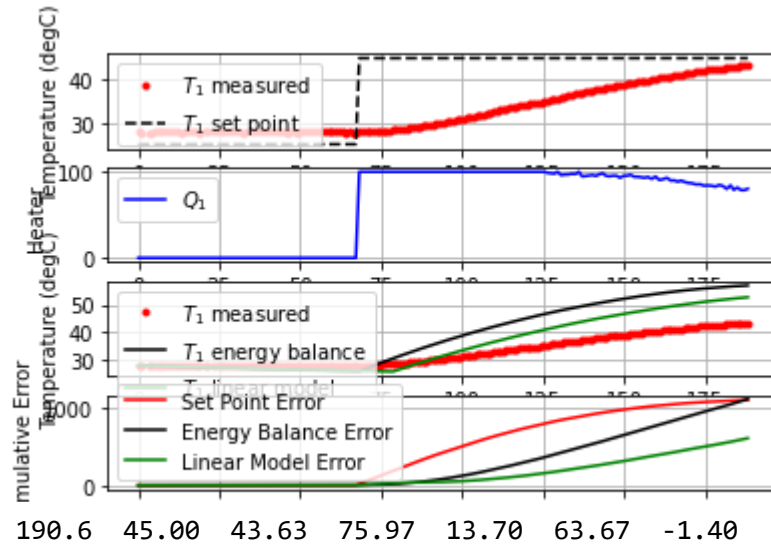
186.0 45.00 43.17 78.88 18.30 62.23 -1.65



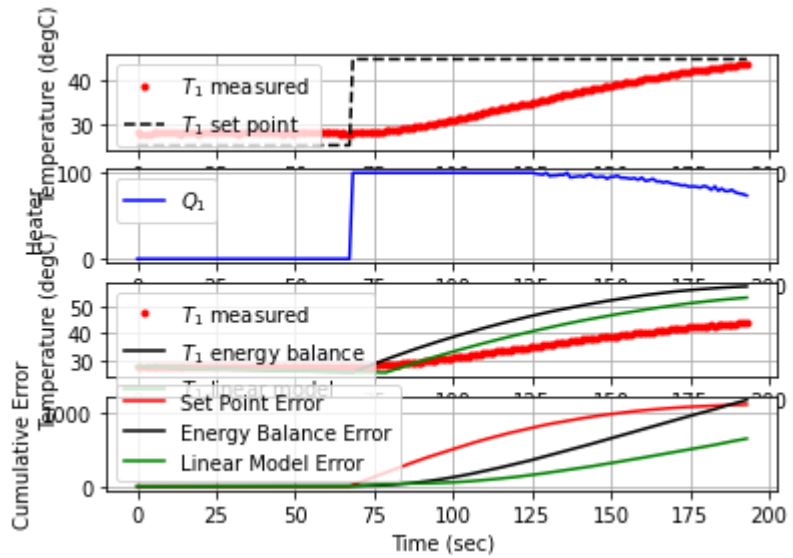
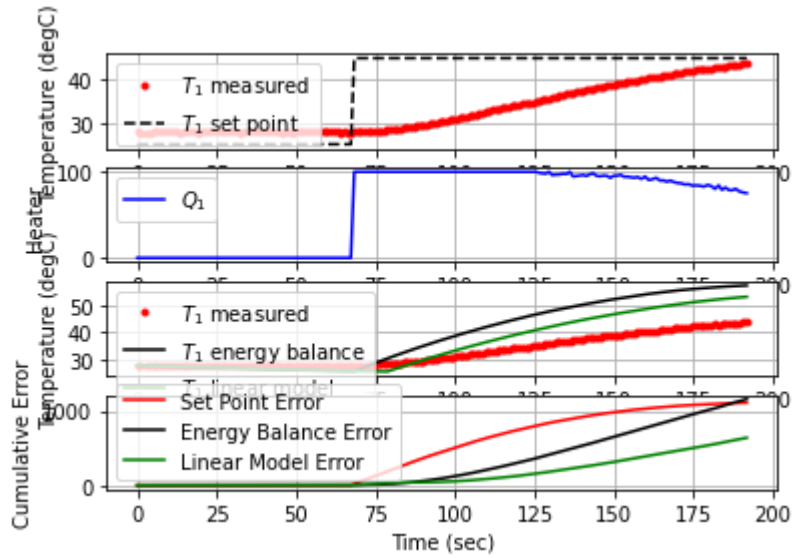
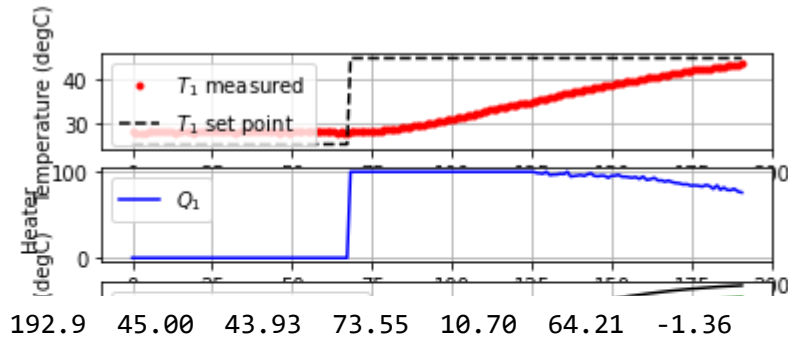
188.2 45.00 43.28 80.27 17.20 62.98 0.09



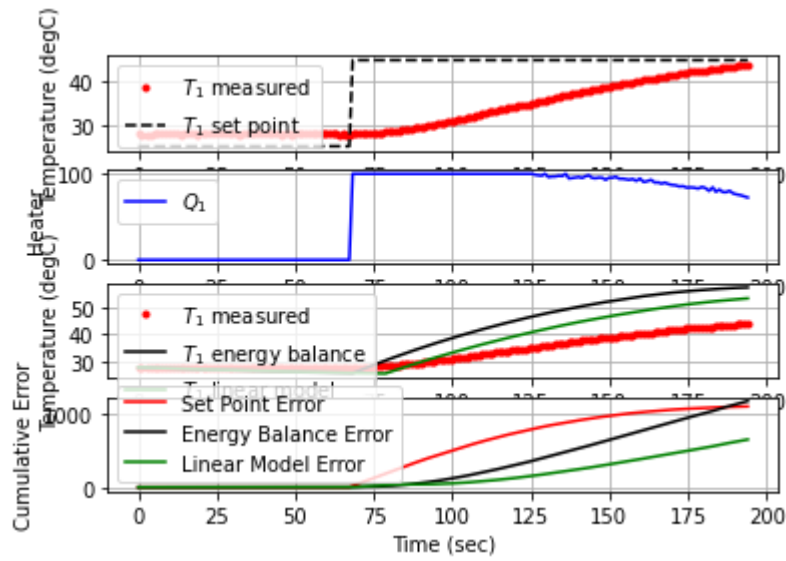
189.4 45.00 43.47 77.11 15.30 63.35 -1.54



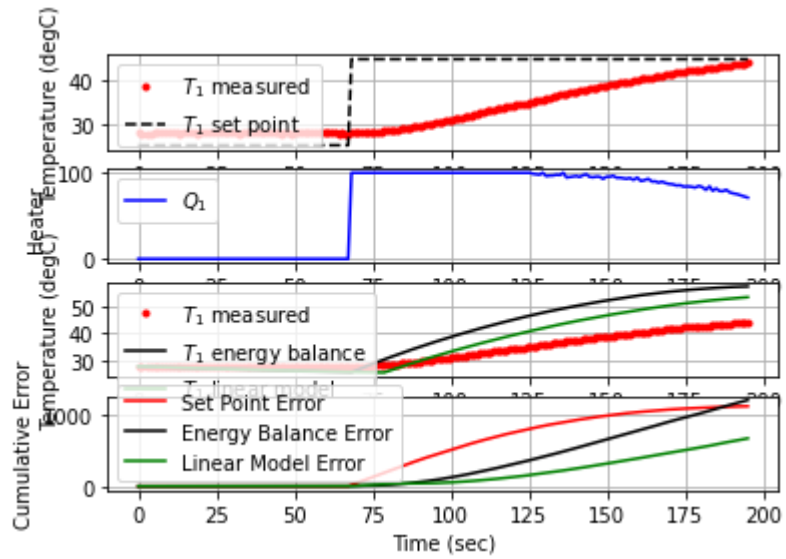
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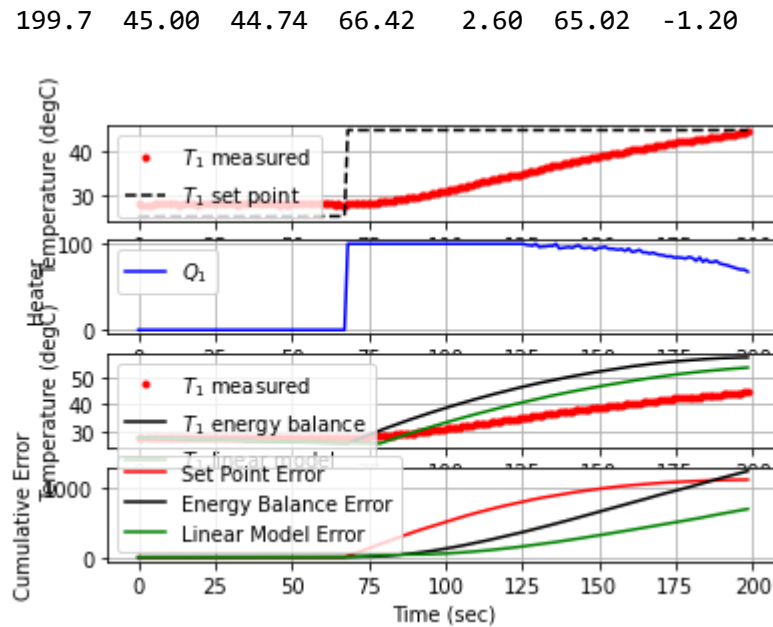
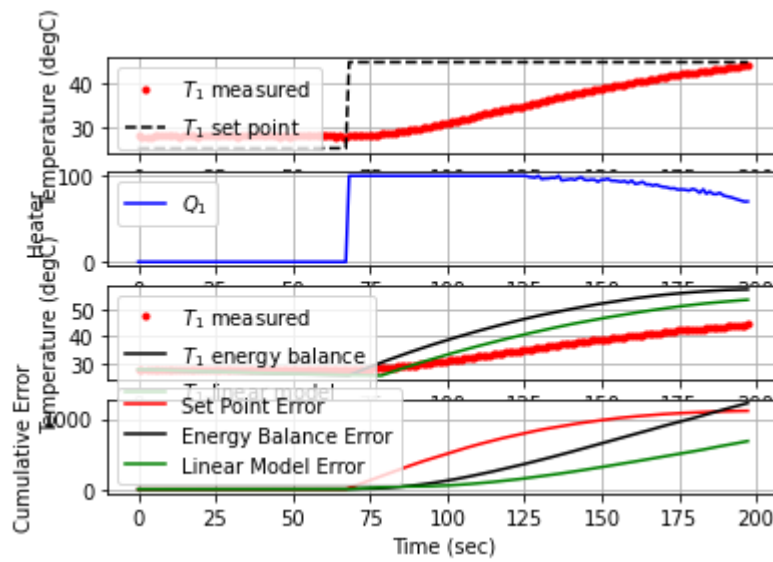
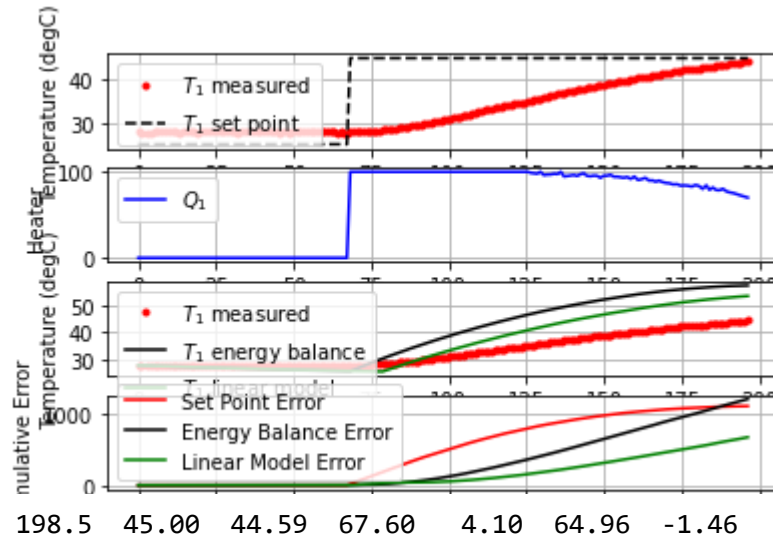
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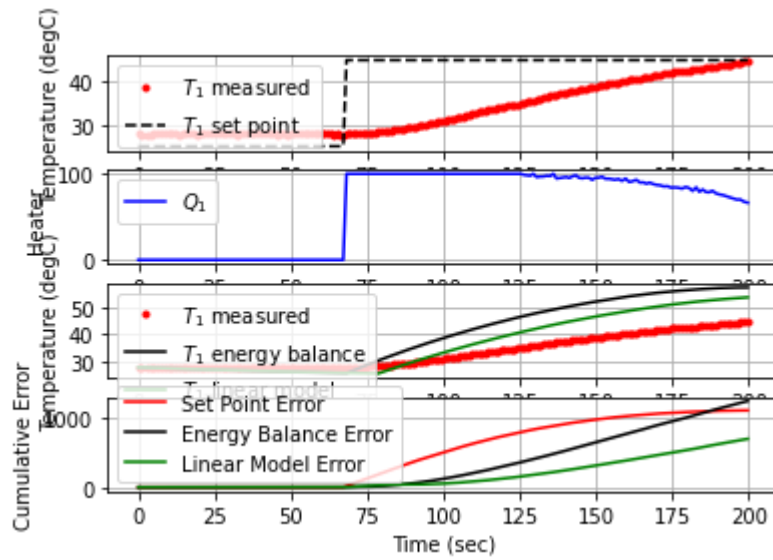


196.2 45.00 44.35 69.98 6.50 64.73 -1.25

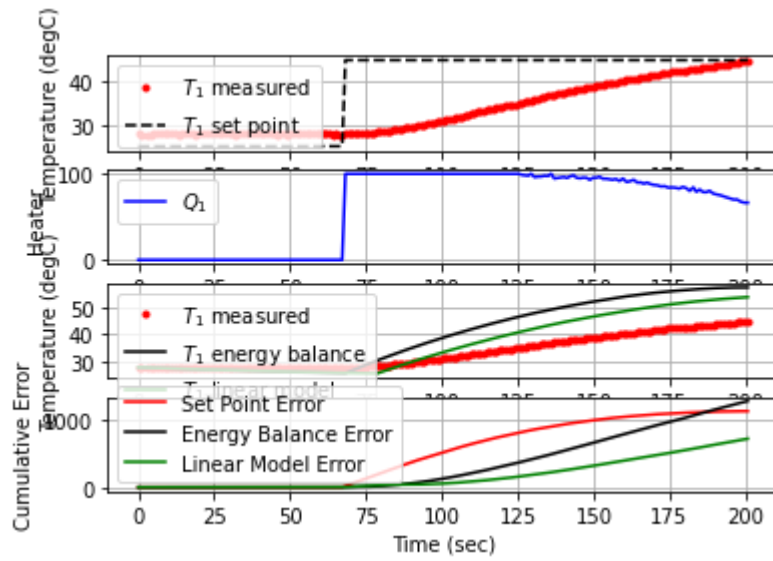


197.3 45.00 44.41 70.19 5.90 64.85 -0.57

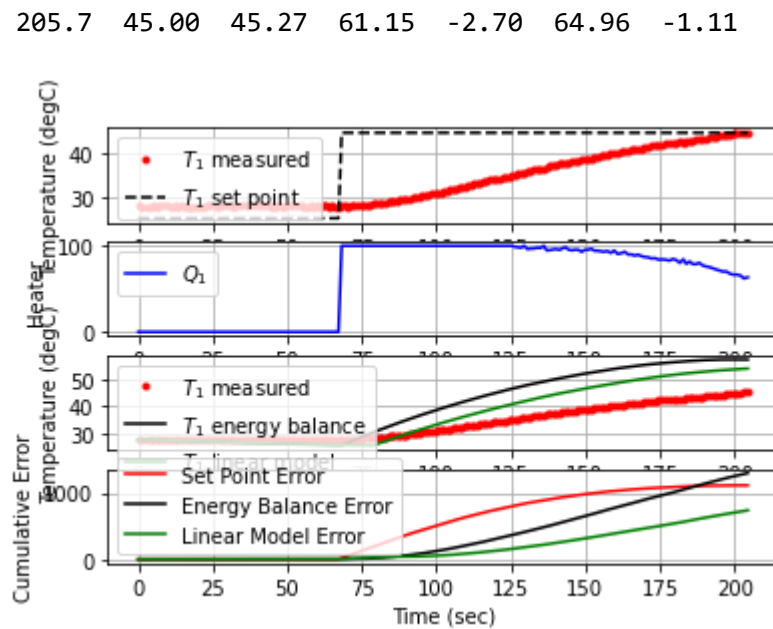
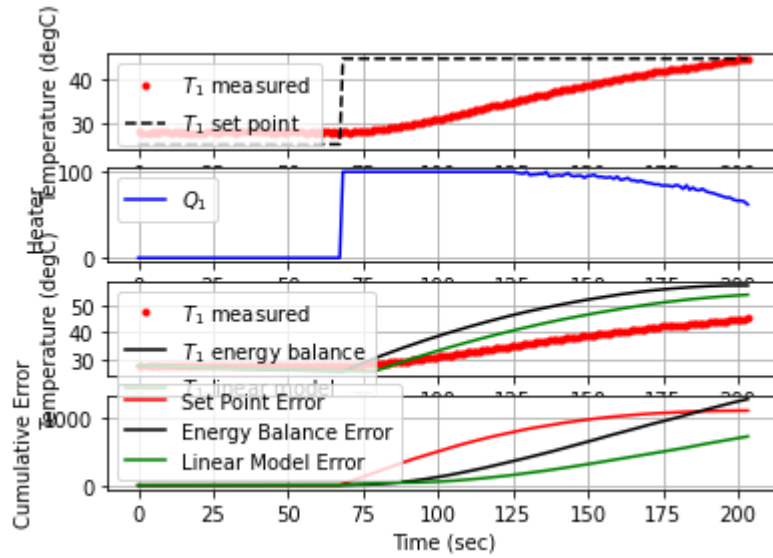
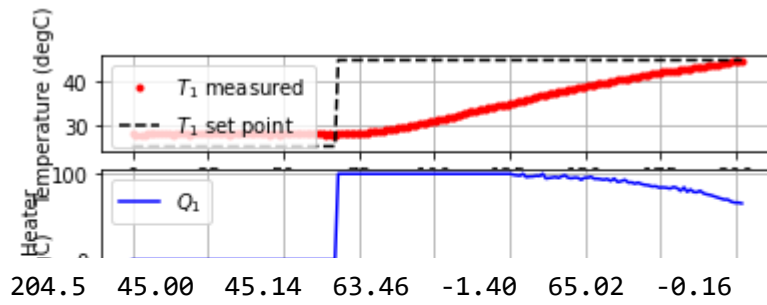




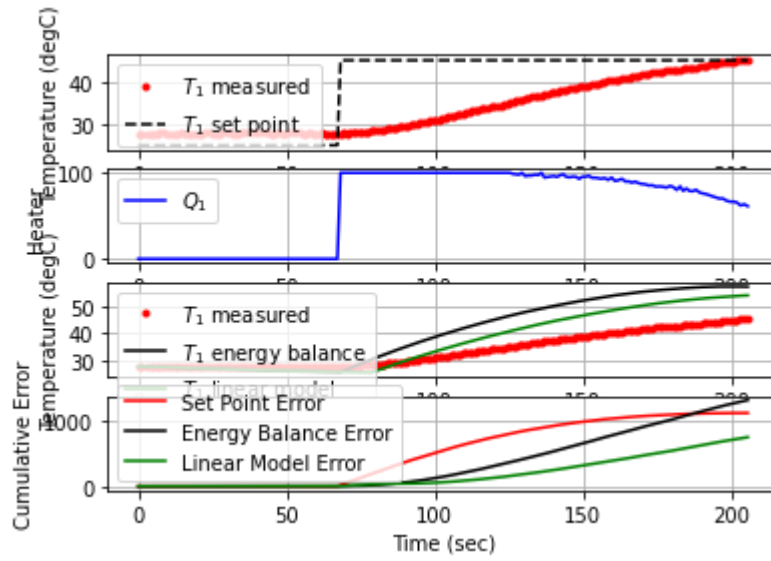
202.0 45.00 44.88 65.61 1.20 65.09 -0.68



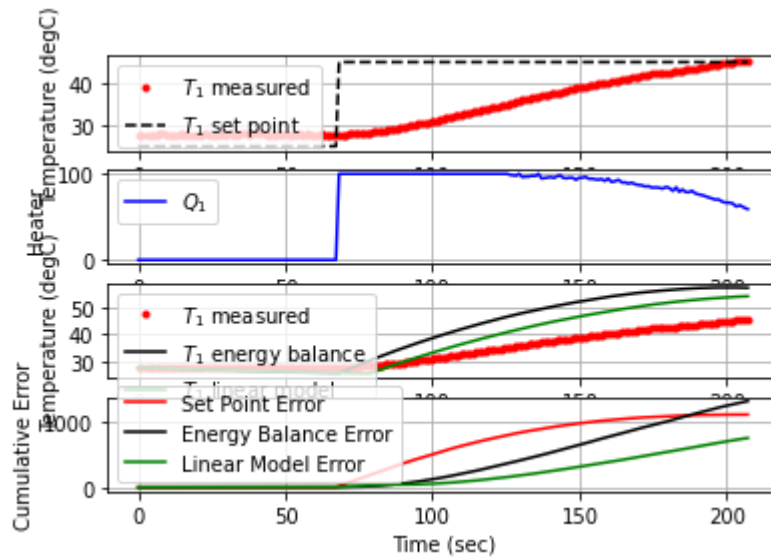
203.3 45.00 45.12 61.99 -1.20 65.06 -1.87



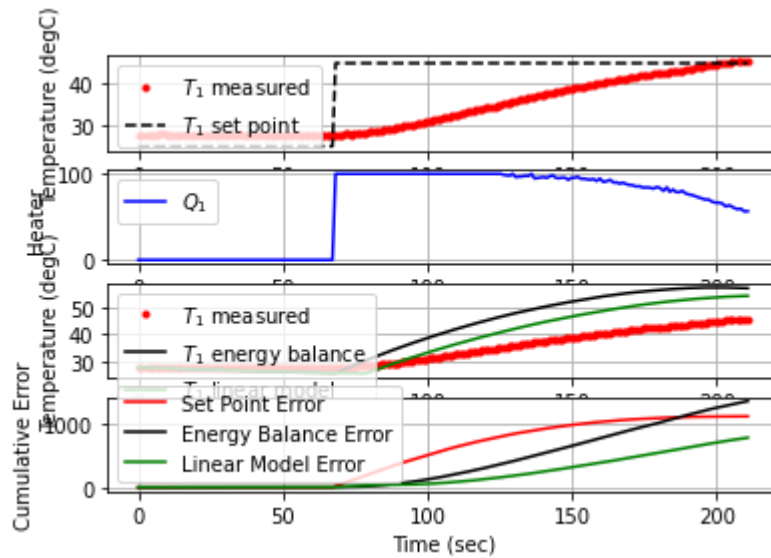
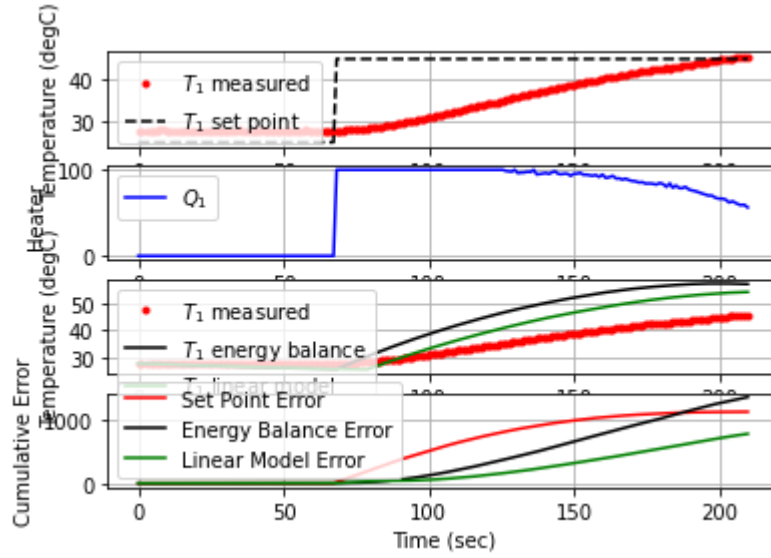
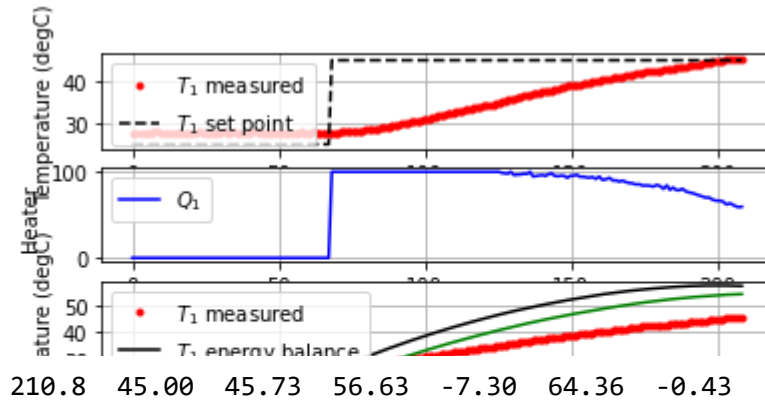
207.2 45.00 45.46 58.94 -4.60 64.83 -1.28



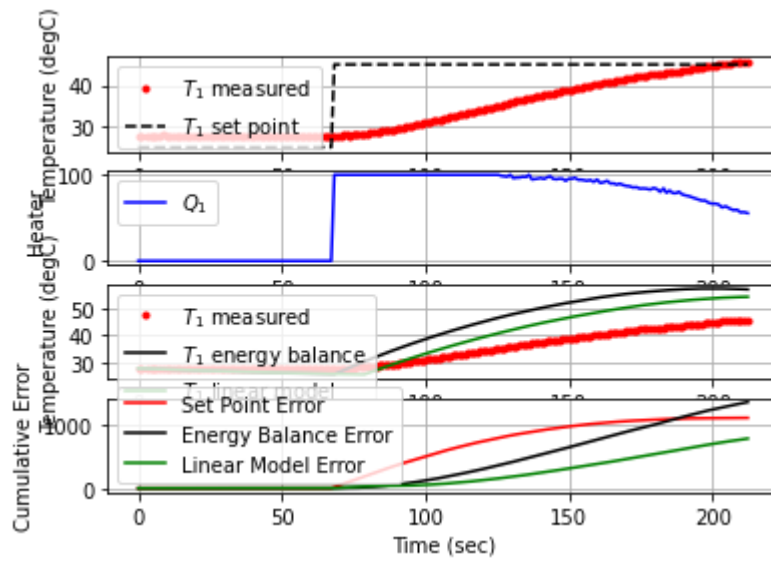
208.5 45.00 45.50 59.39 -5.00 64.69 -0.31



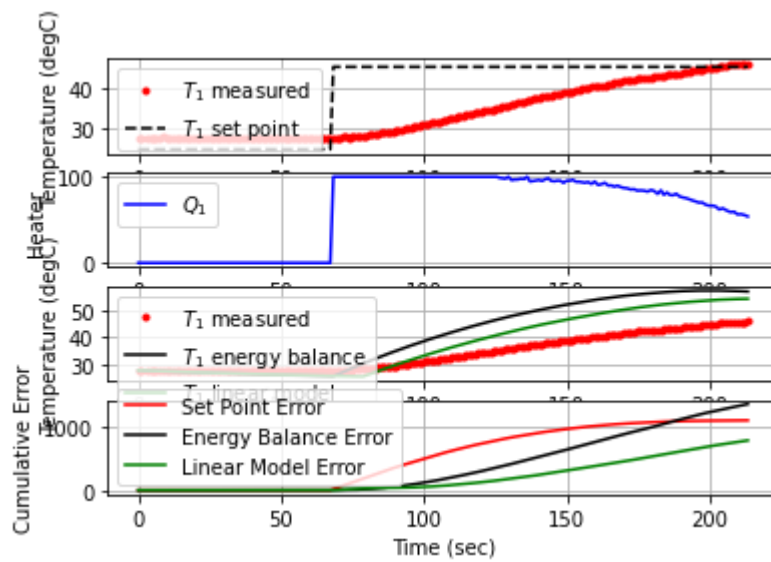
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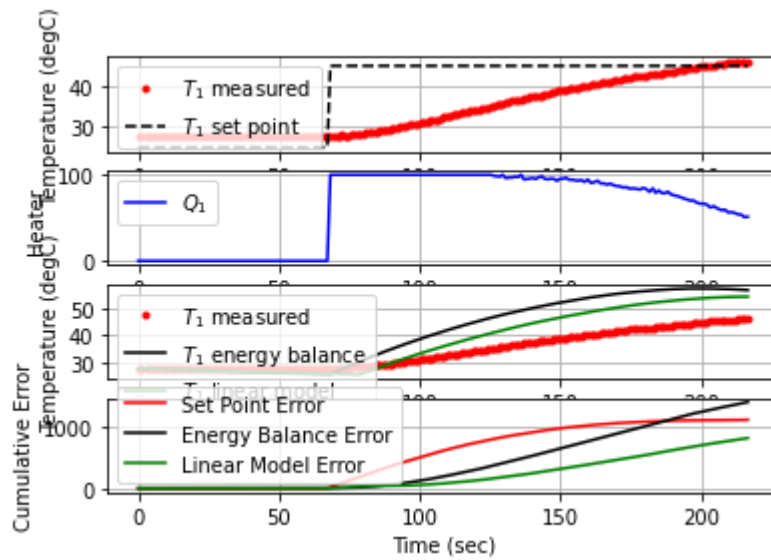
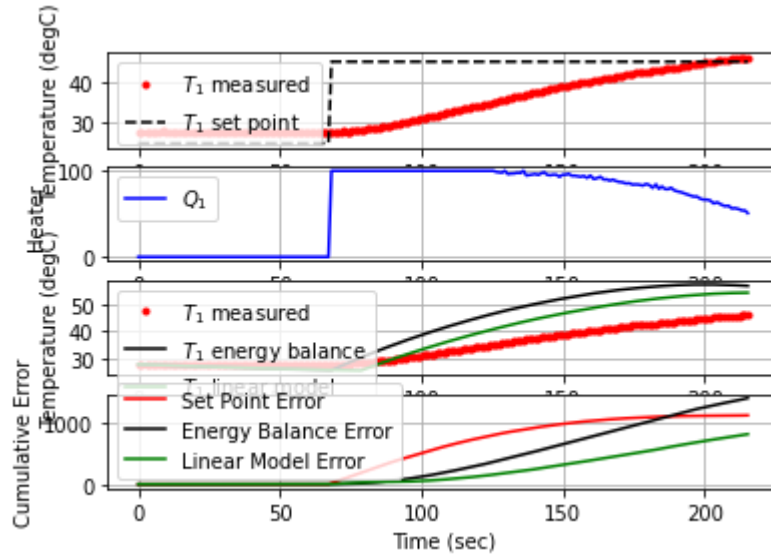
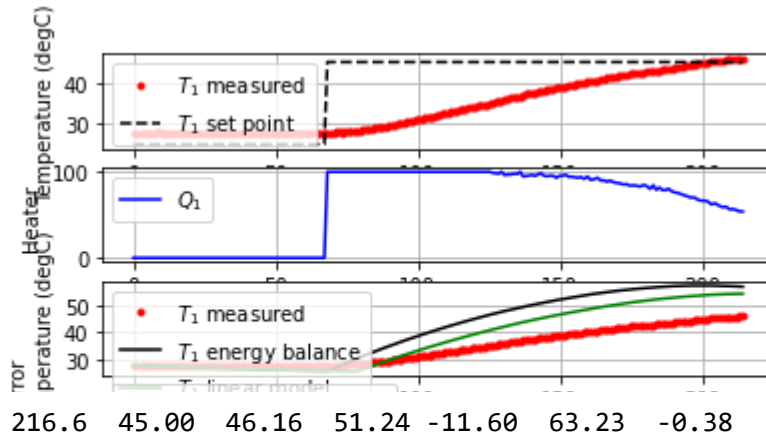
213.2 45.00 45.91 53.91 -9.10 63.95 -0.94

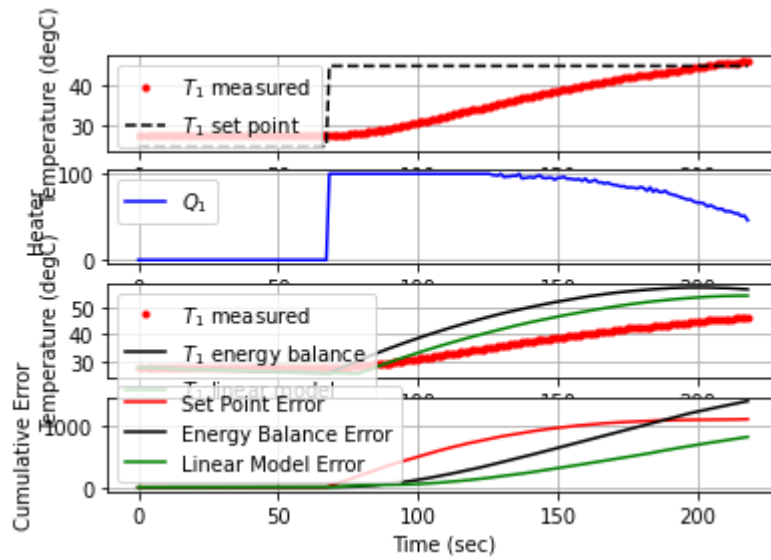


214.3 45.00 45.95 53.87 -9.50 63.75 -0.38

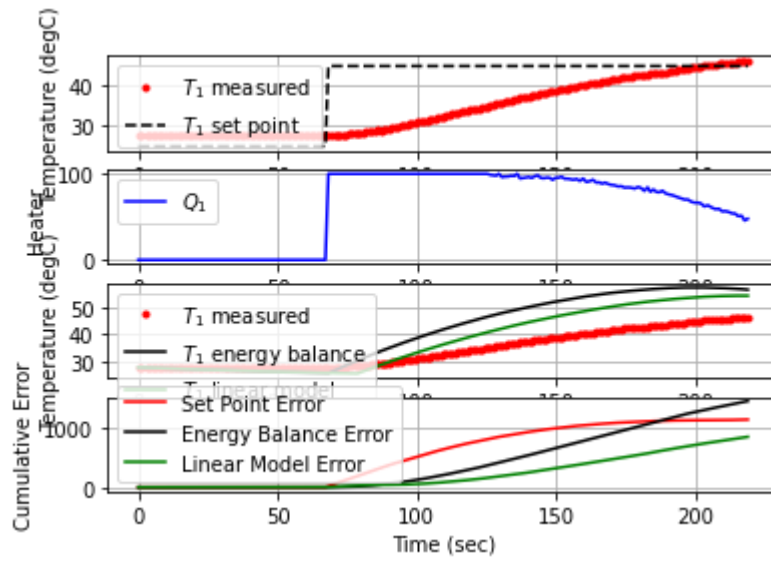


215.3 45.00 46.11 50.82 -11.10 63.53 -1.61

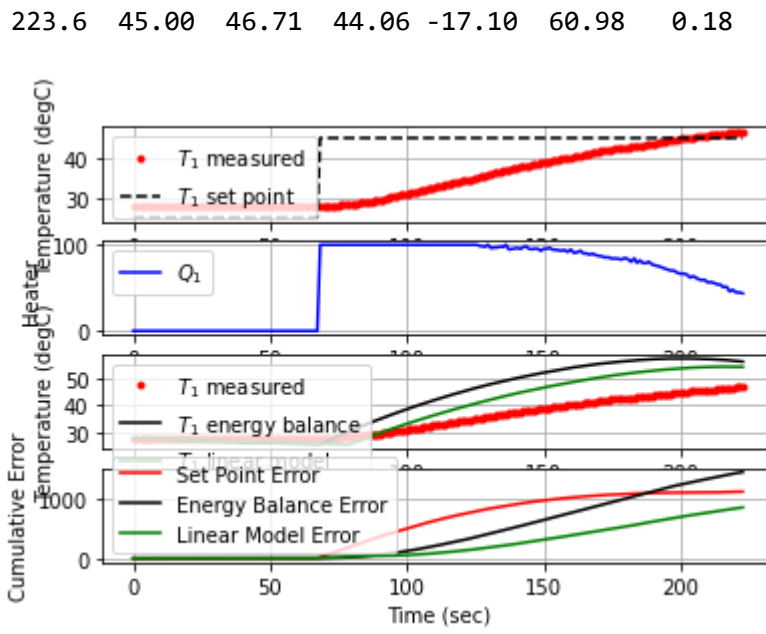
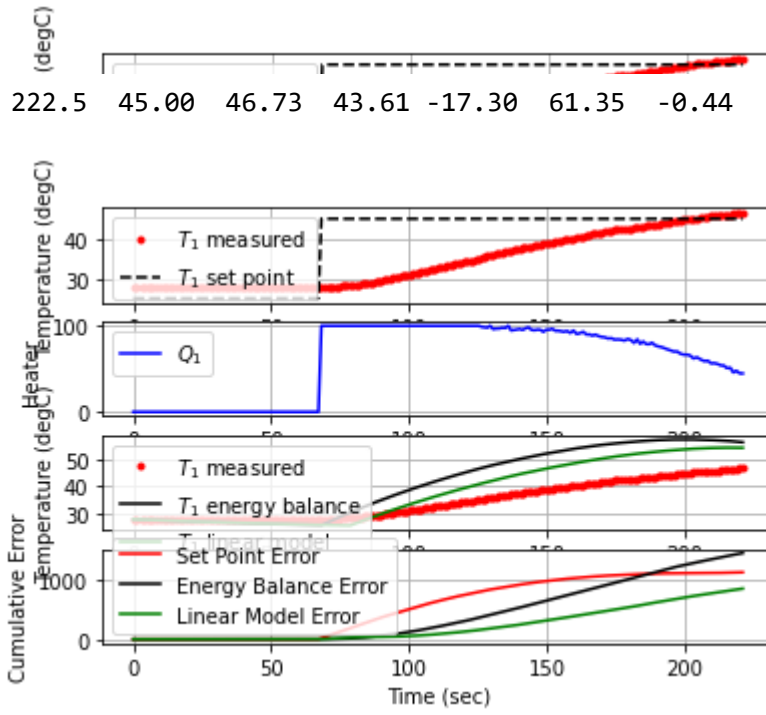




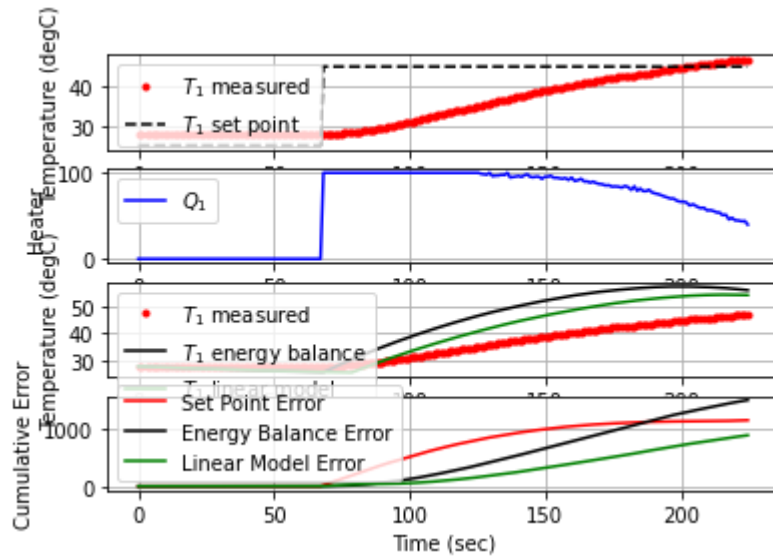
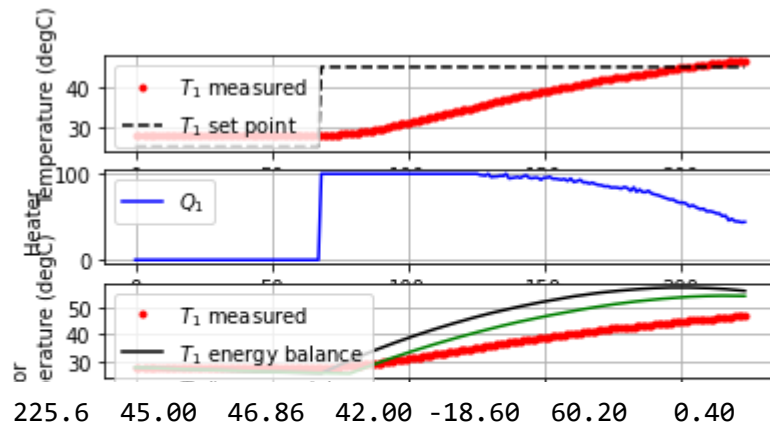
220.0 45.00 46.62 44.72 -16.20 62.19 -1.27



221.1 45.00 46.67 44.67 -16.70 61.82 -0.45

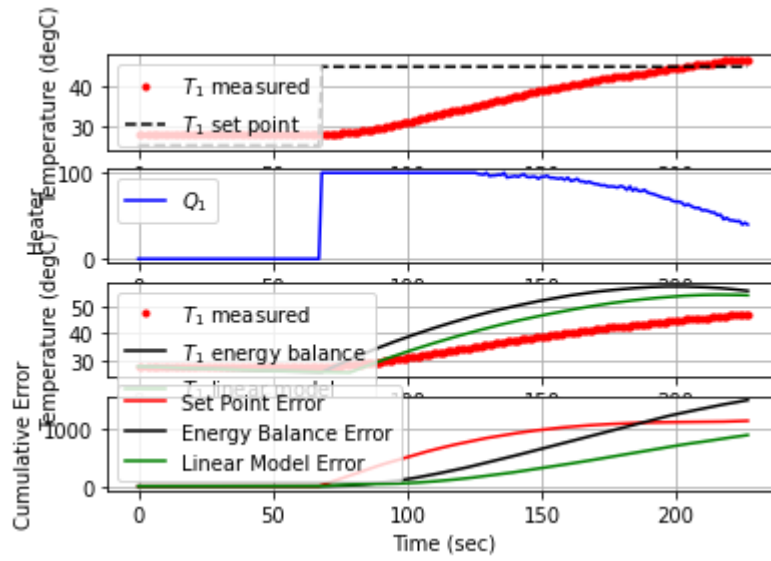


224.6 45.00 46.90 39.80 -19.00 60.57 -1.77

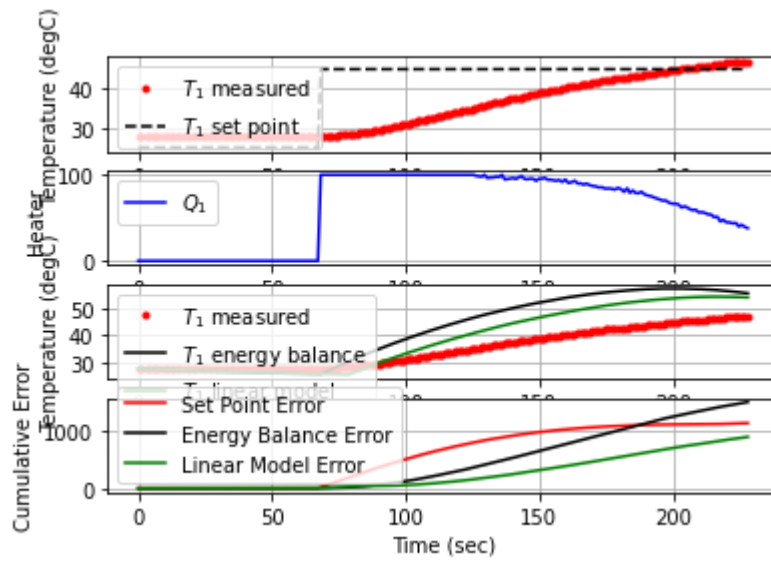


226.6 45.00 46.93 39.82 -19.30 59.81 -0.69

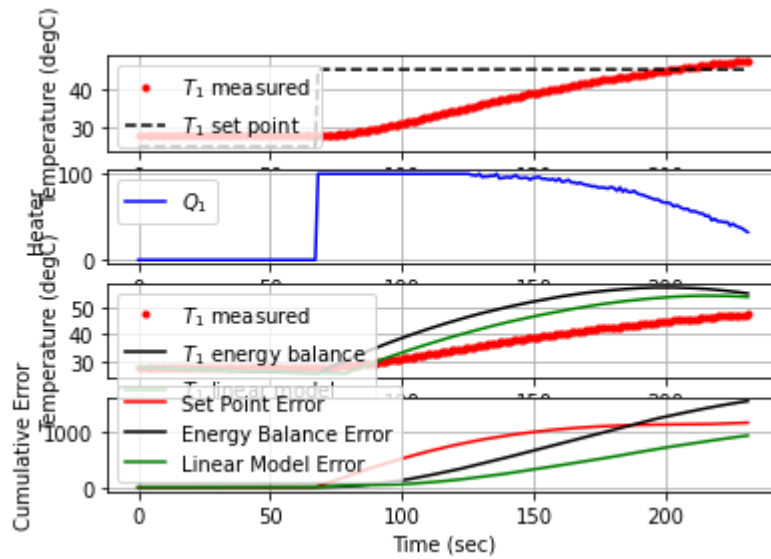
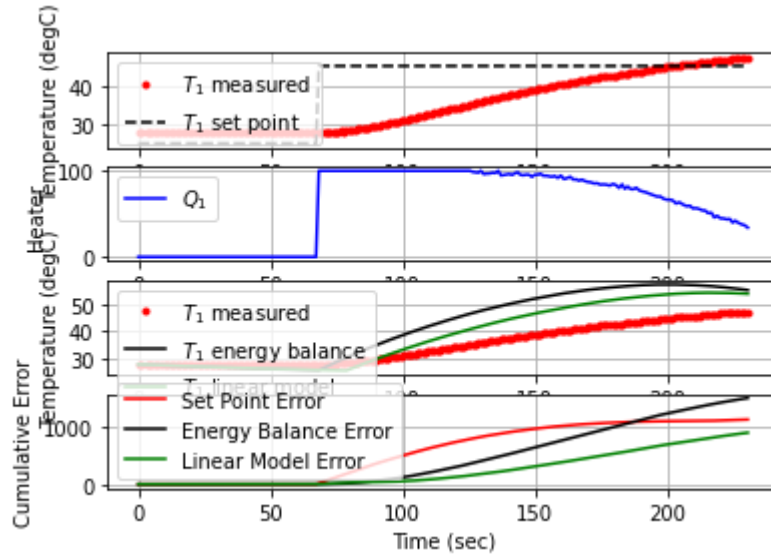
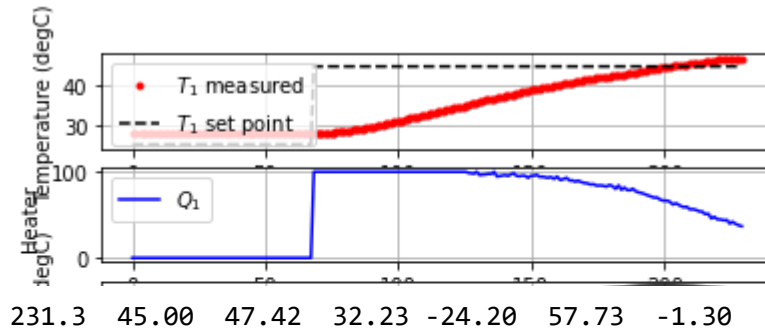
228.0 45.00 47.05 37.86 -20.50 59.27 -0.91

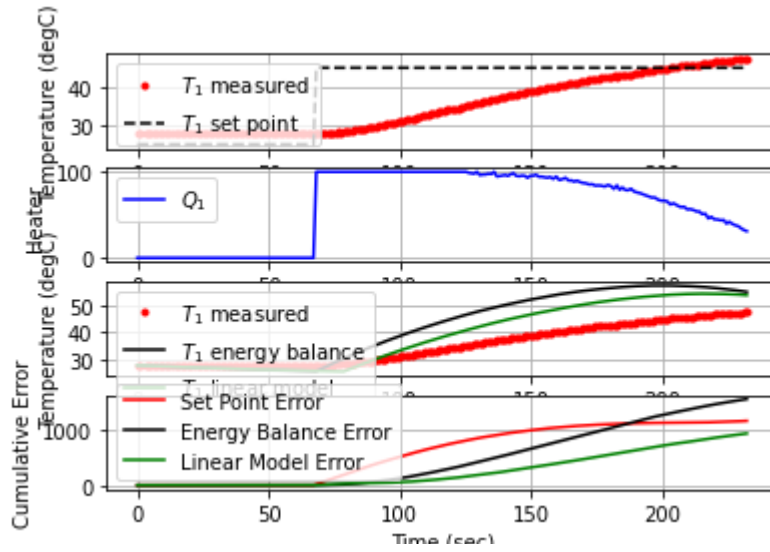


229.1 45.00 47.13 36.78 -21.30 58.77 -0.68

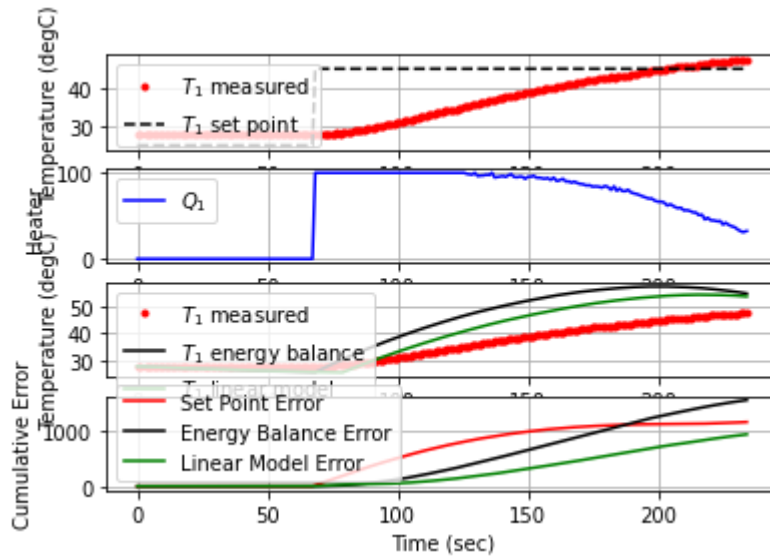


230.3 45.00 47.29 33.99 -22.90 58.22 -1.33

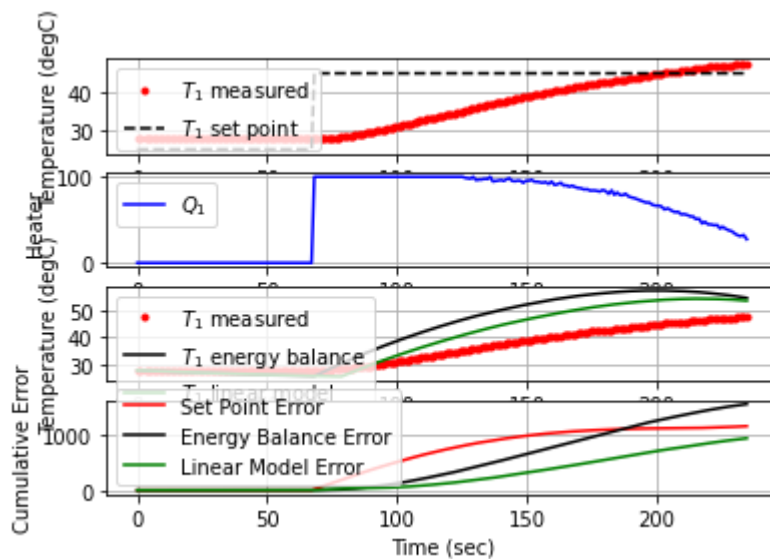




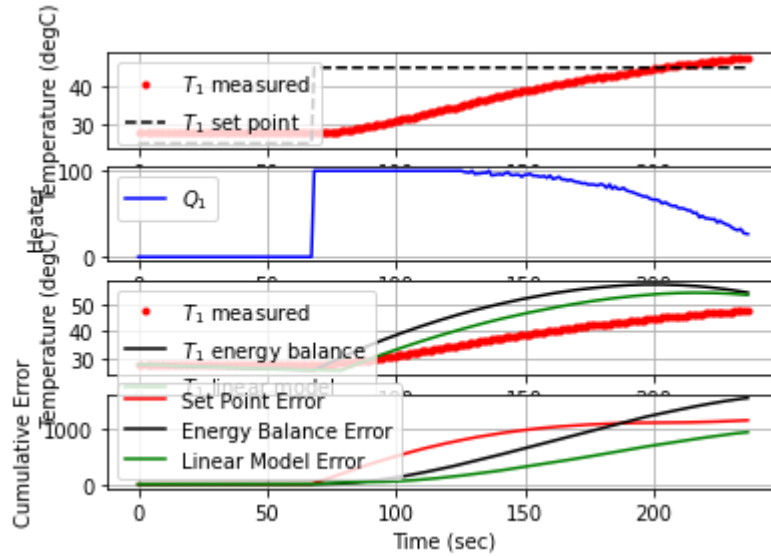
234.9 45.00 47.67 27.44 -26.70 55.91 -1.77



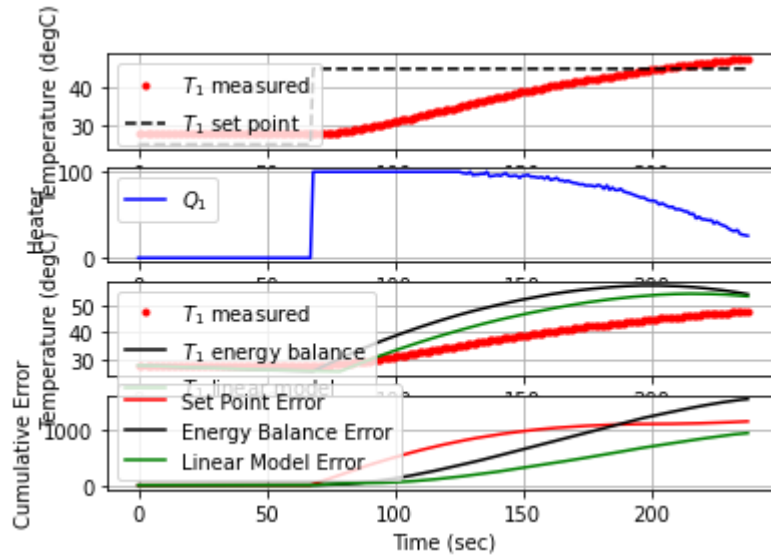
236.4 45.00 47.78 26.54 -27.80 55.06 -0.73



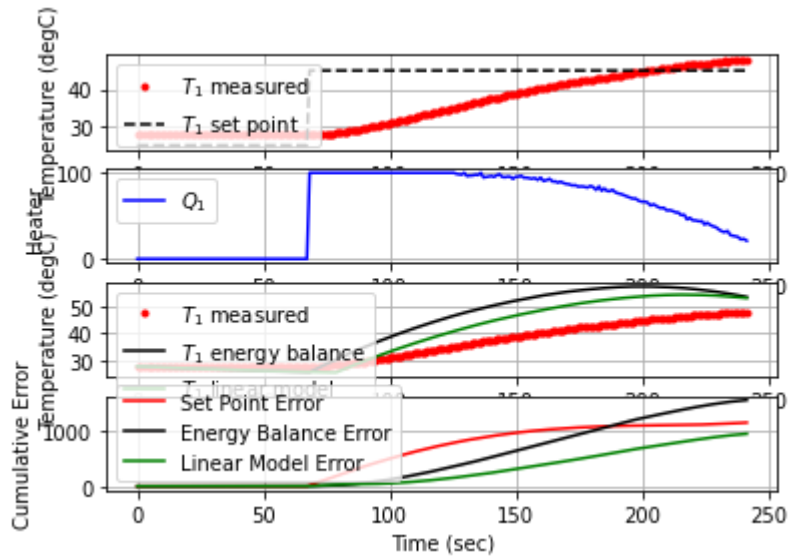
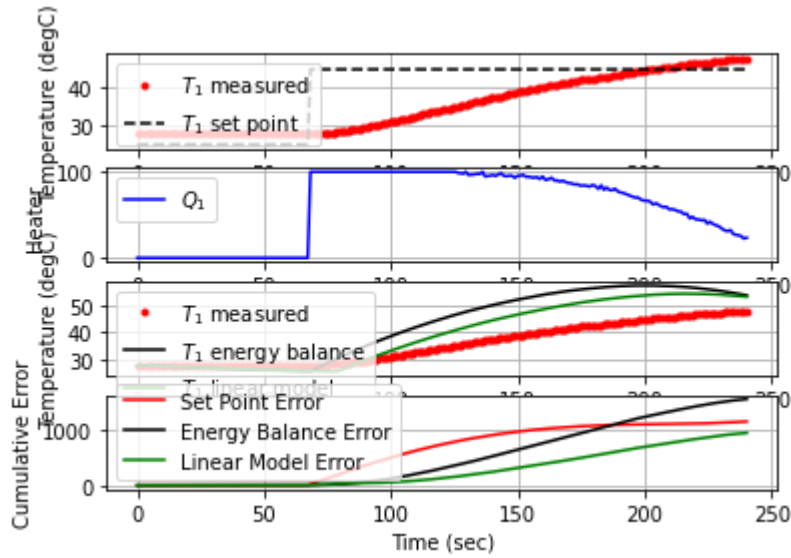
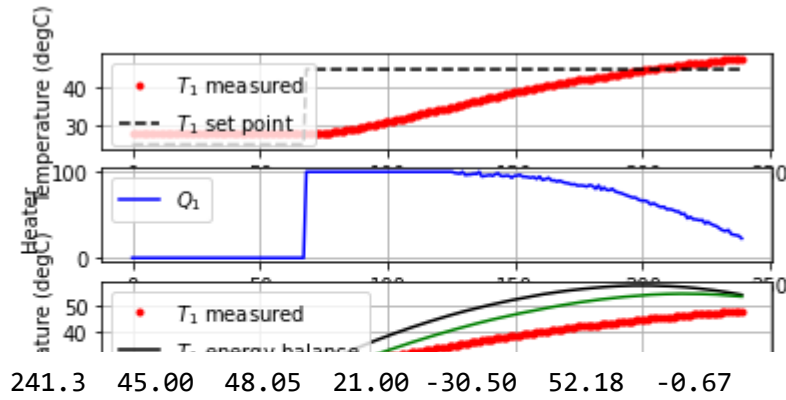
237.8 45.00 47.83 25.63 -28.30 54.30 -0.37

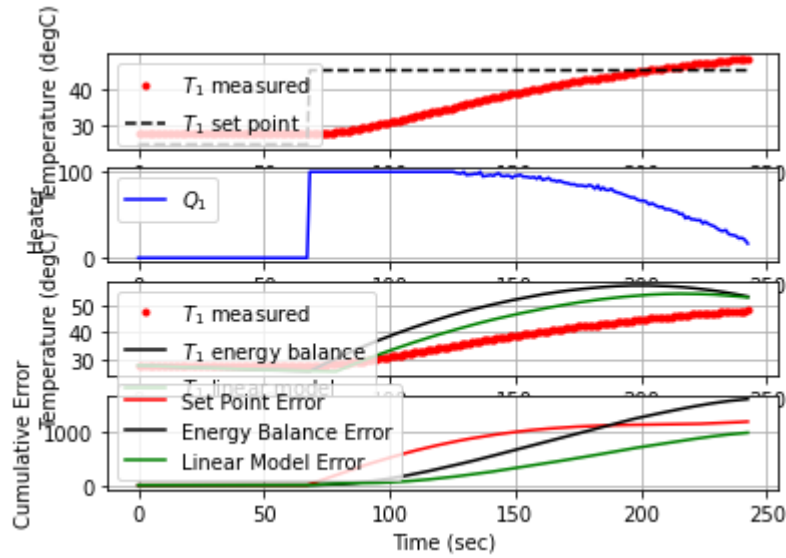


239.0 45.00 47.98 22.52 -29.80 53.60 -1.28

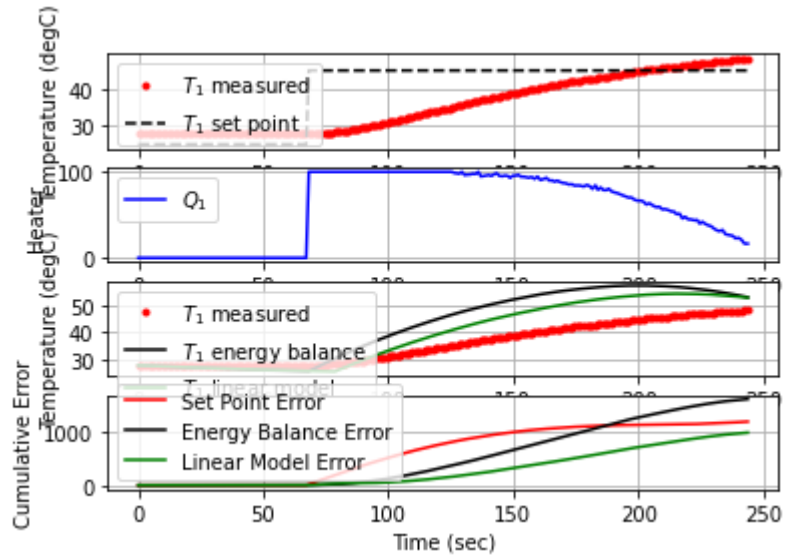


240.1 45.00 47.97 23.29 -29.70 52.90 0.09

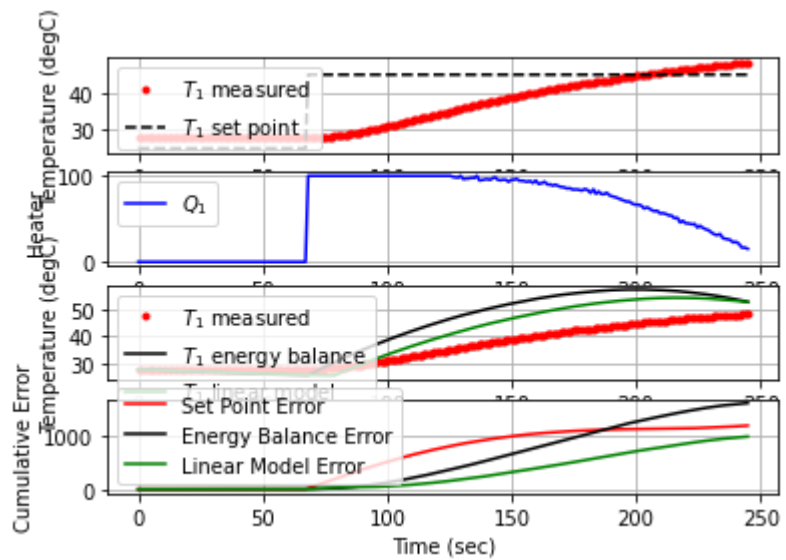




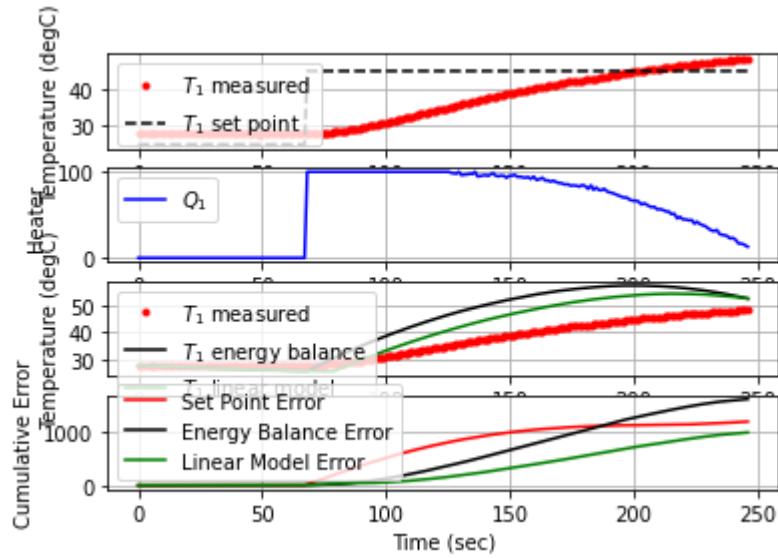
244.9 45.00 48.41 15.14 -34.10 49.82 -0.57



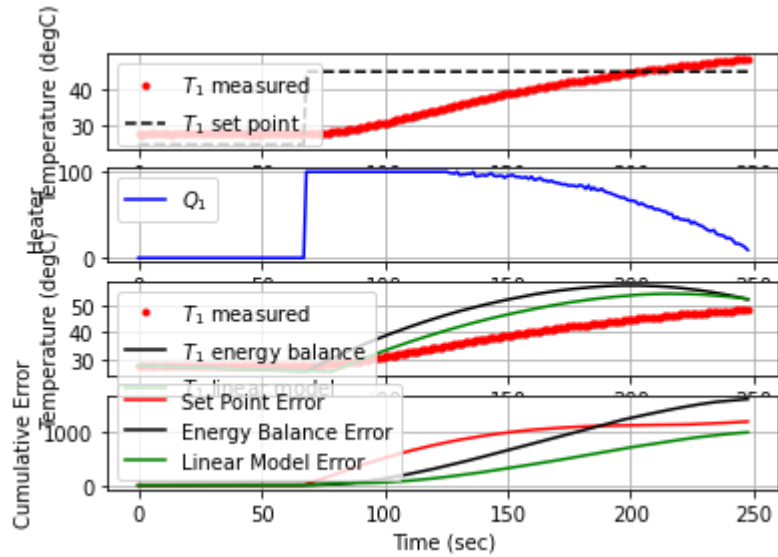
246.2 45.00 48.52 12.85 -35.20 48.88 -0.83



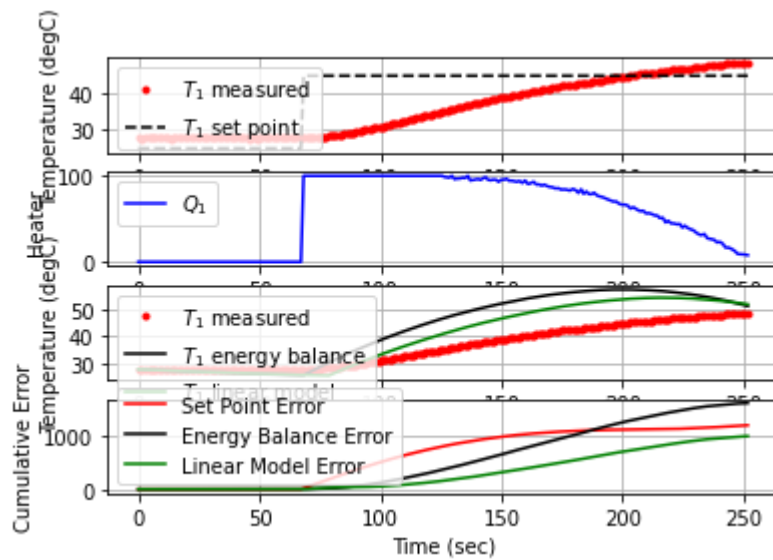
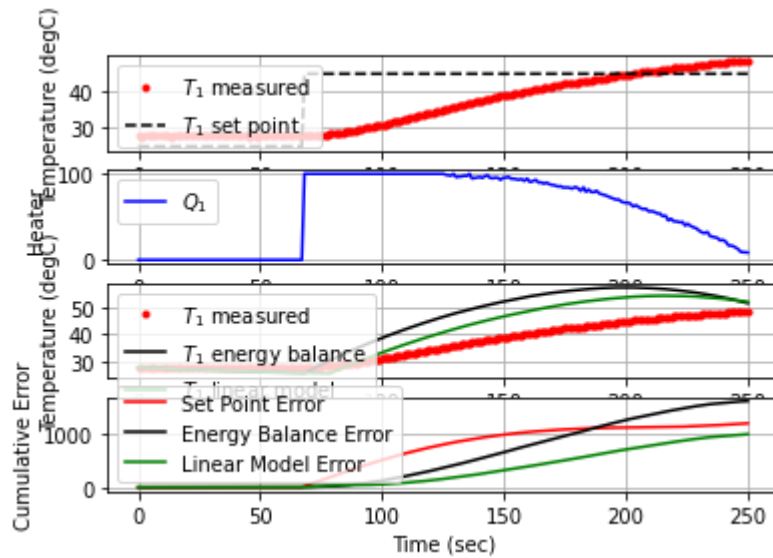
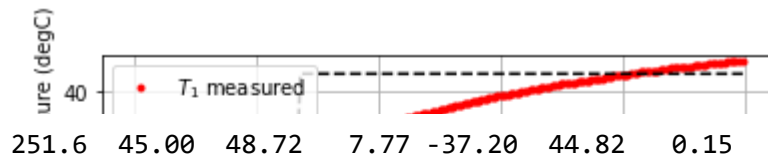
247.5 45.00 48.72 9.18 -37.20 47.89 -1.51

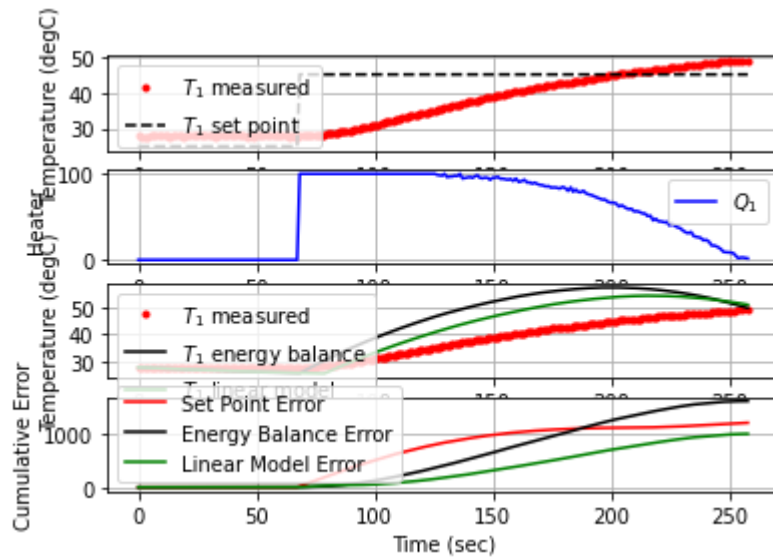
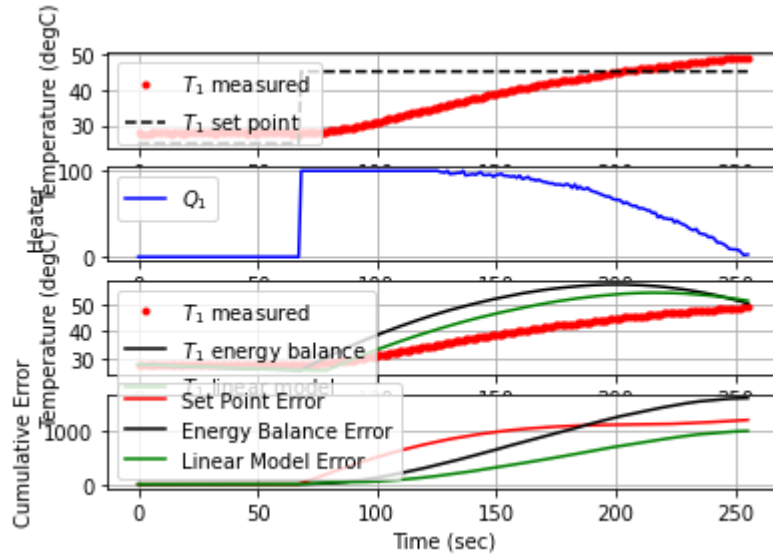
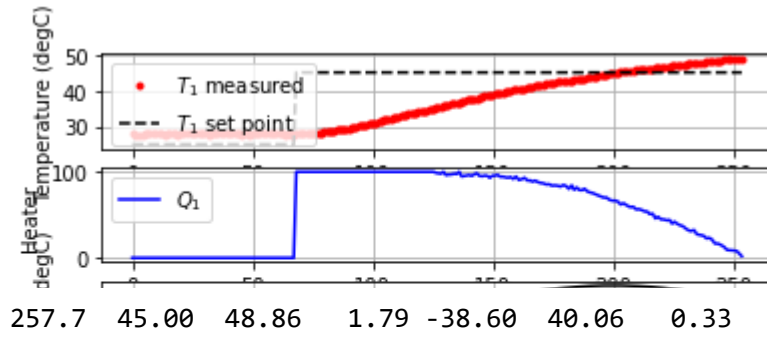


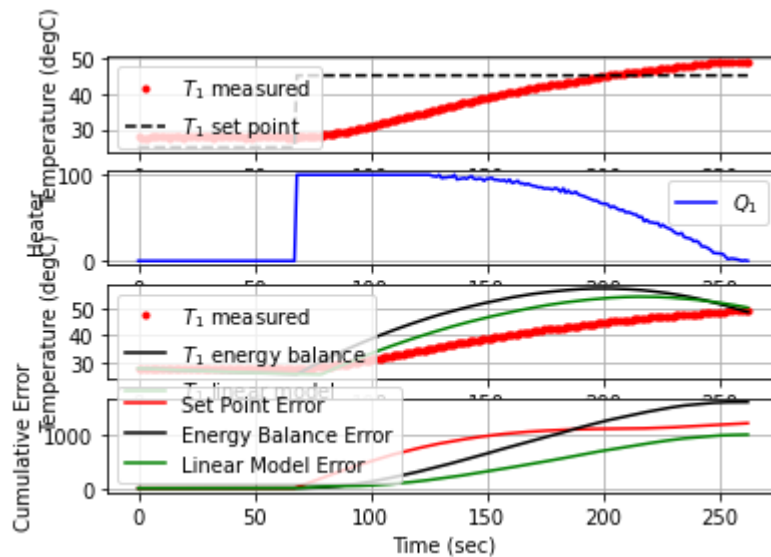
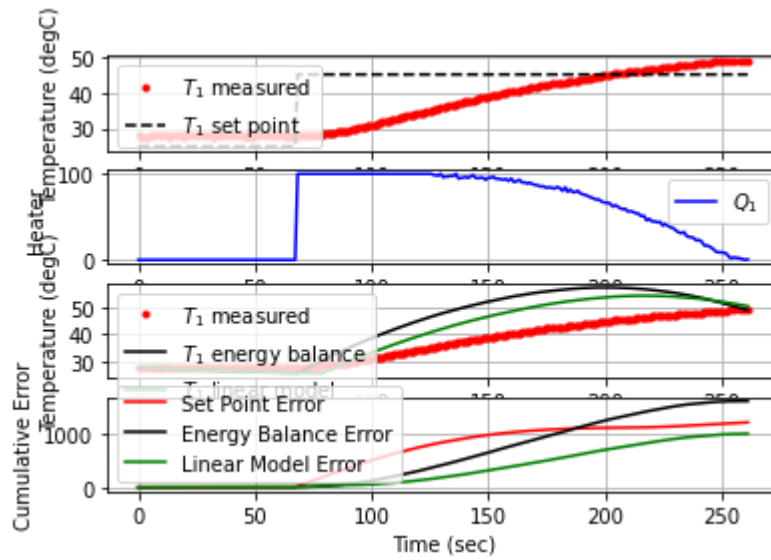
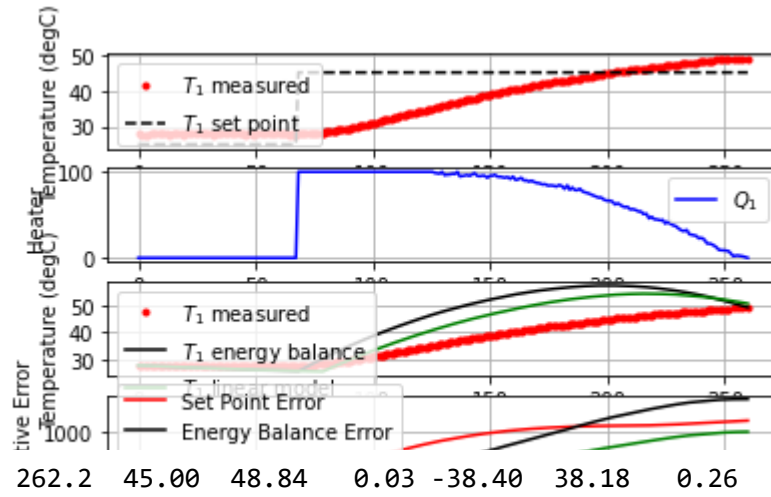
249.0 45.00 48.76 8.90 -37.60 46.76 -0.27

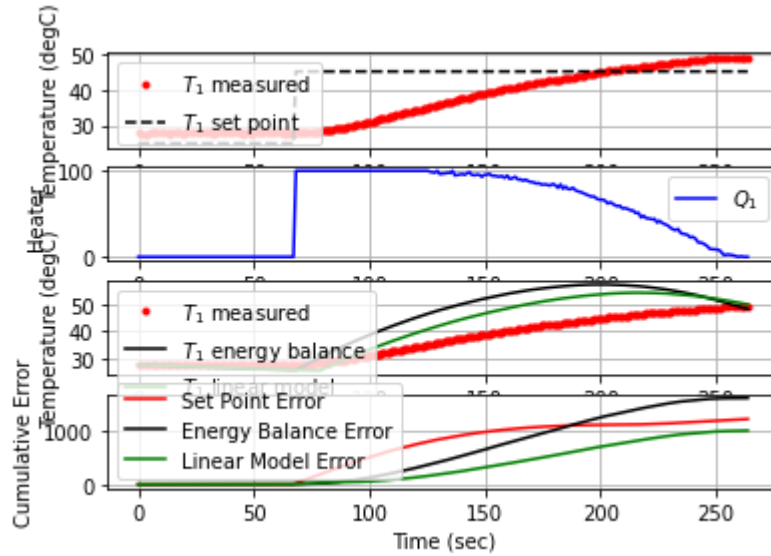


250.3 45.00 48.74 8.54 -37.40 45.79 0.15

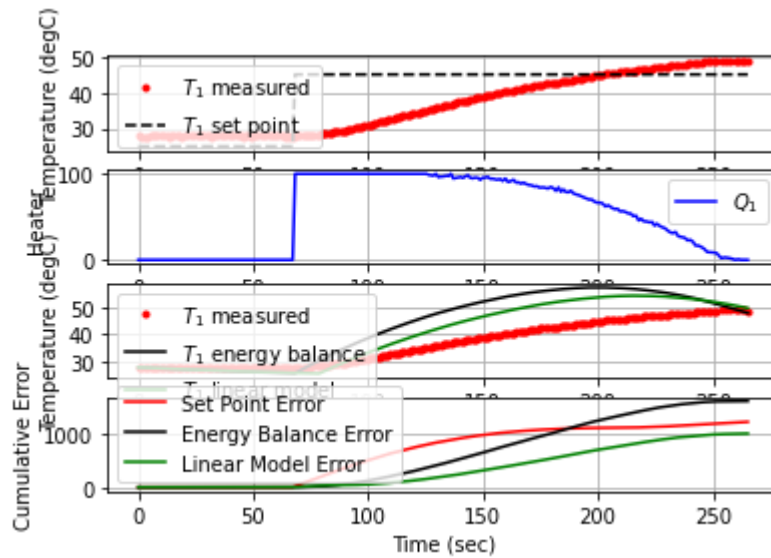




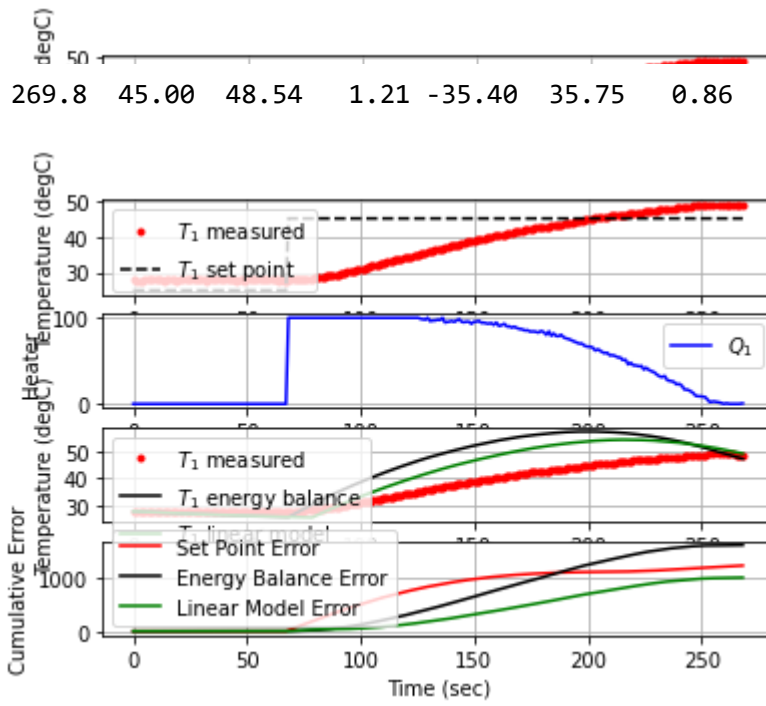




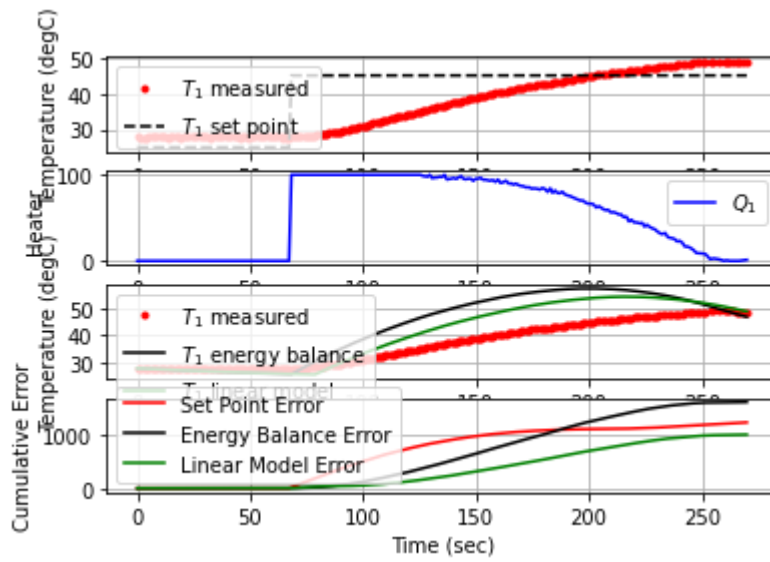
266.5 45.00 48.77 0.00 -37.70 38.18 0.38



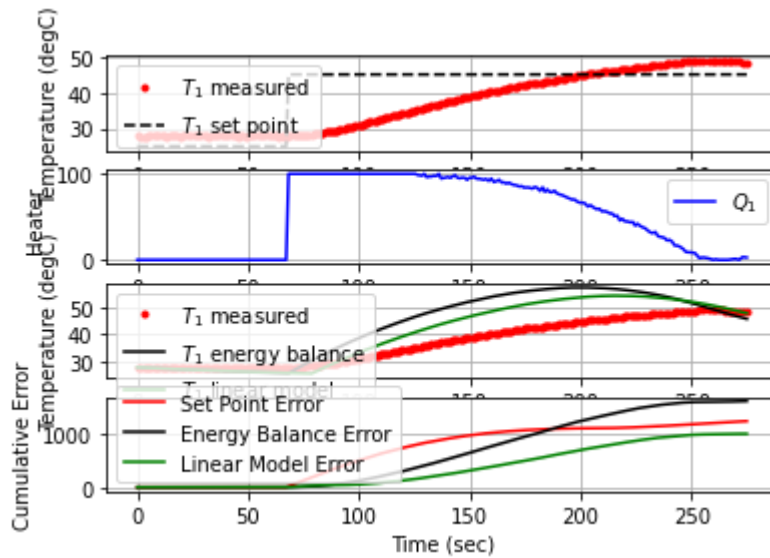
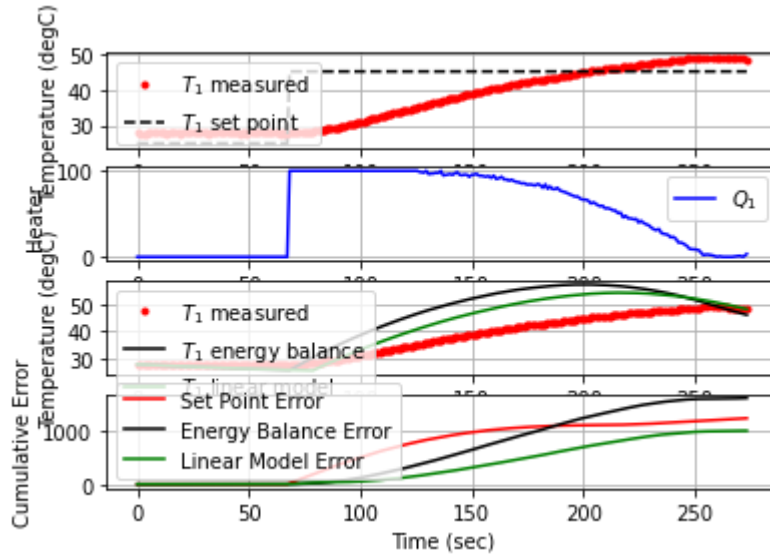
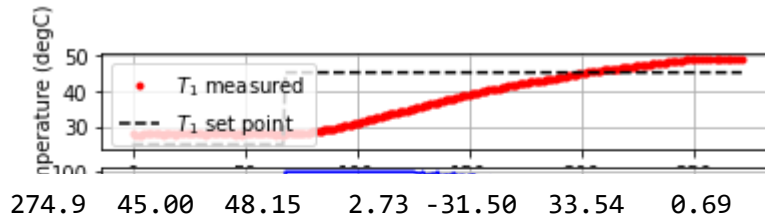
268.1 45.00 48.69 0.59 -36.90 36.99 0.50

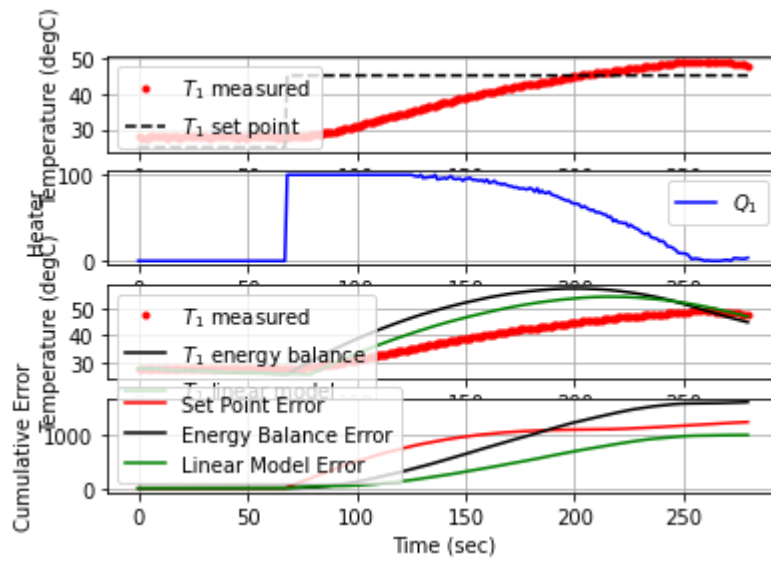
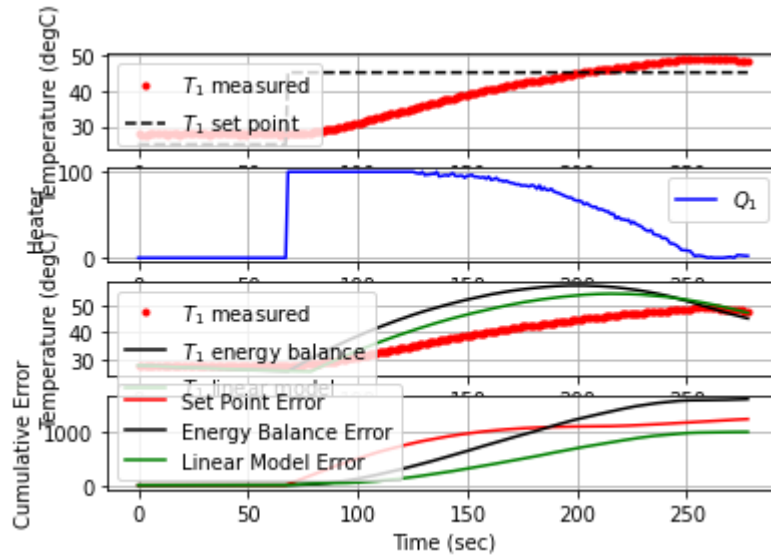
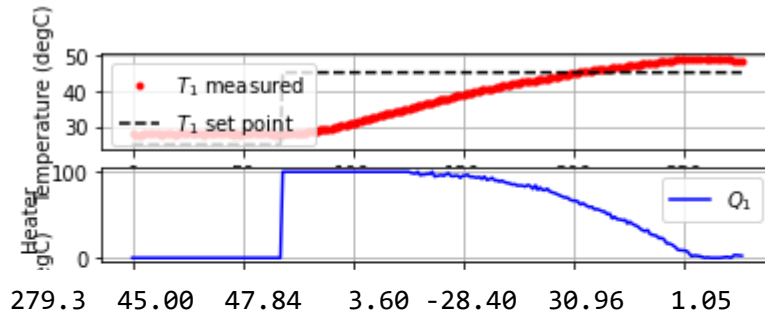


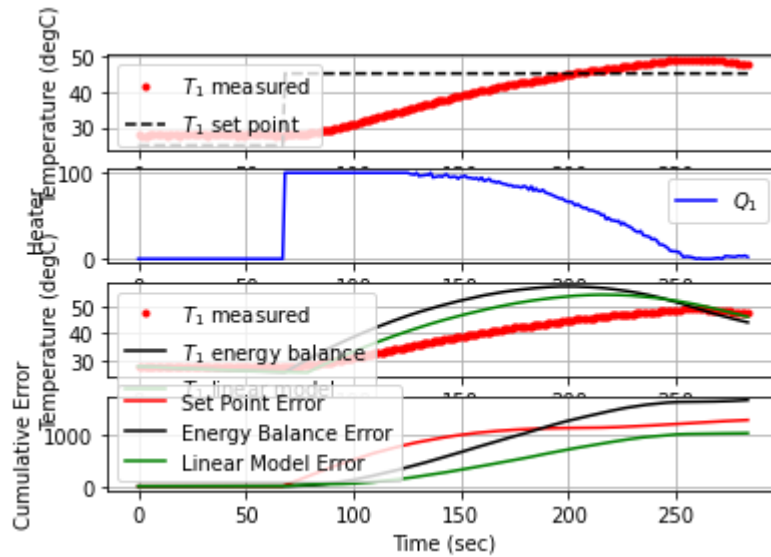
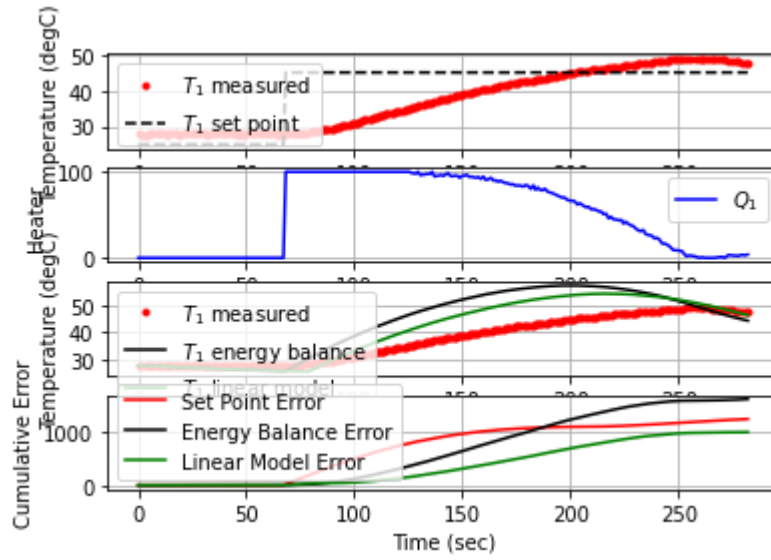
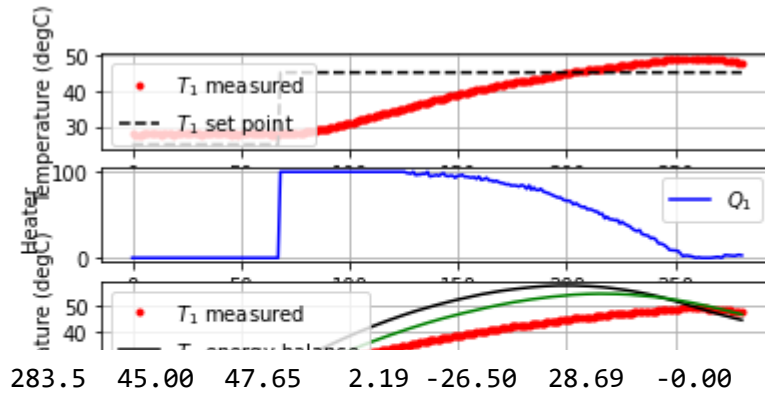
271.5 45.00 48.50 0.00 -35.00 35.75 0.24

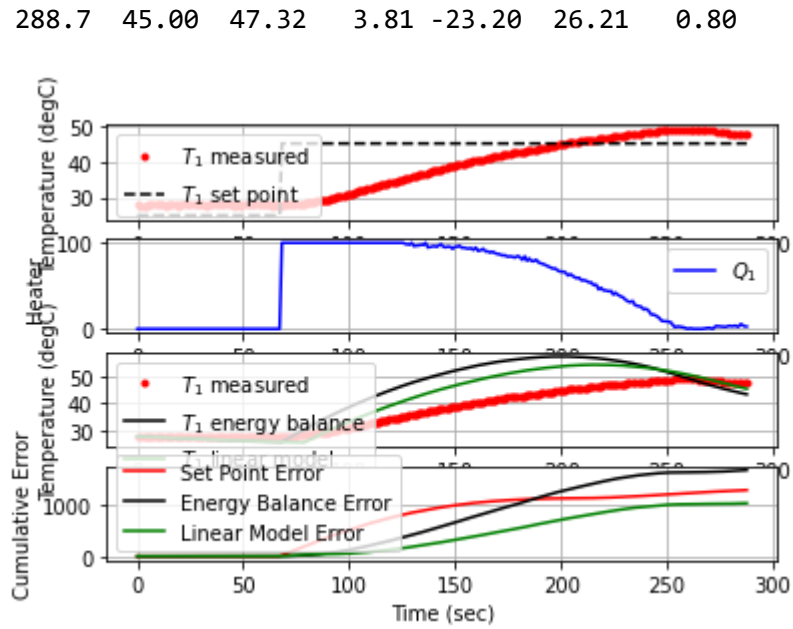
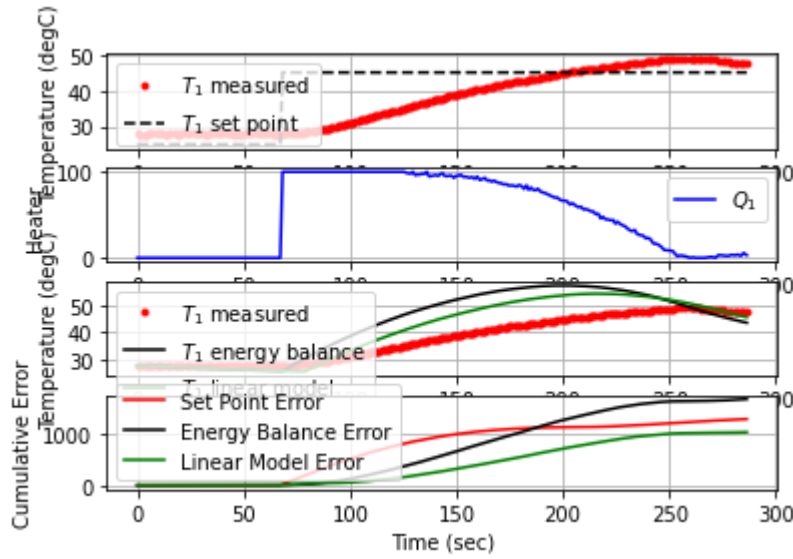
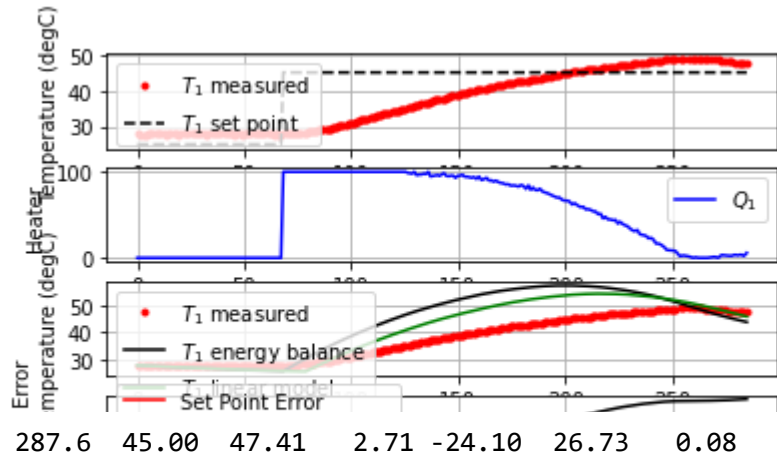


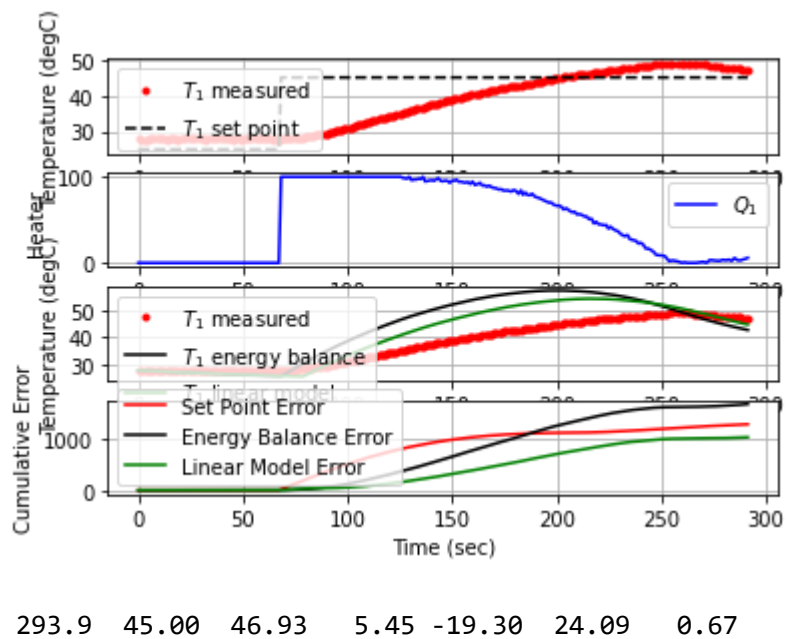
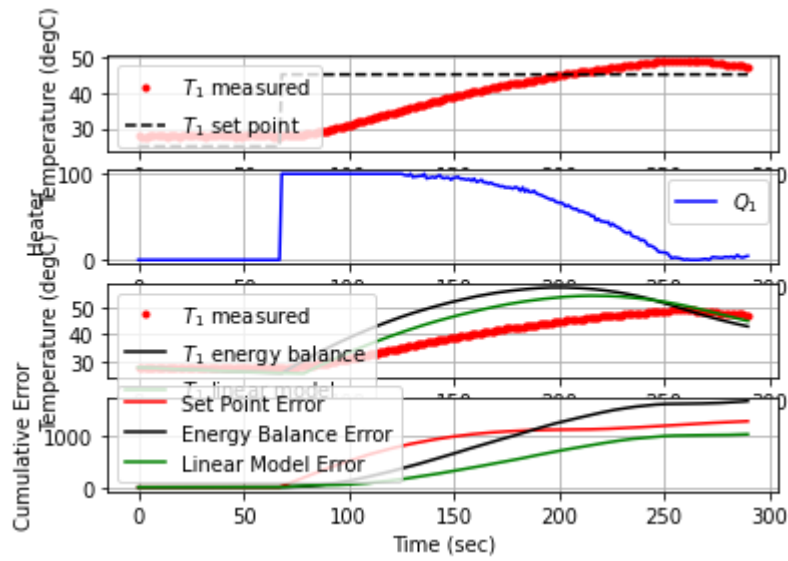
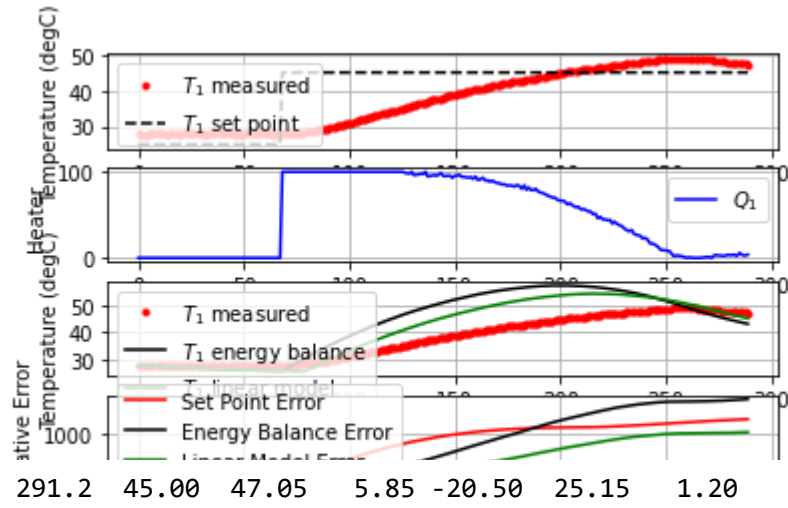
273.1 45.00 48.28 3.32 -32.80 34.72 1.40

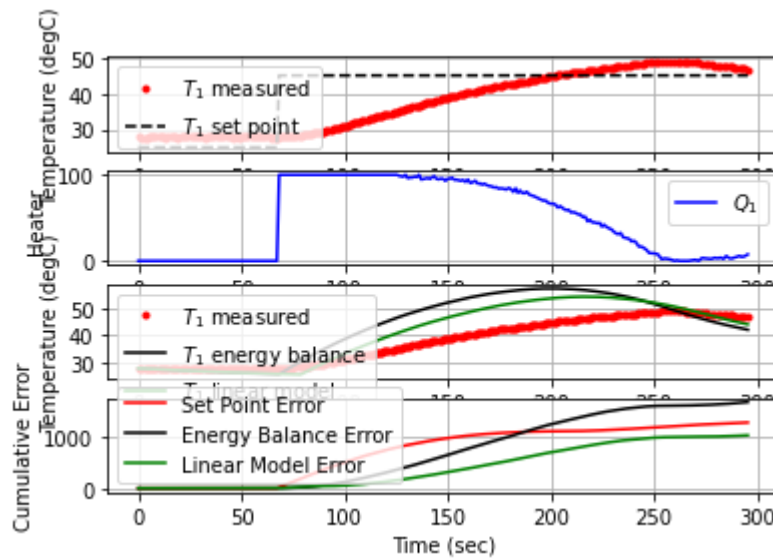
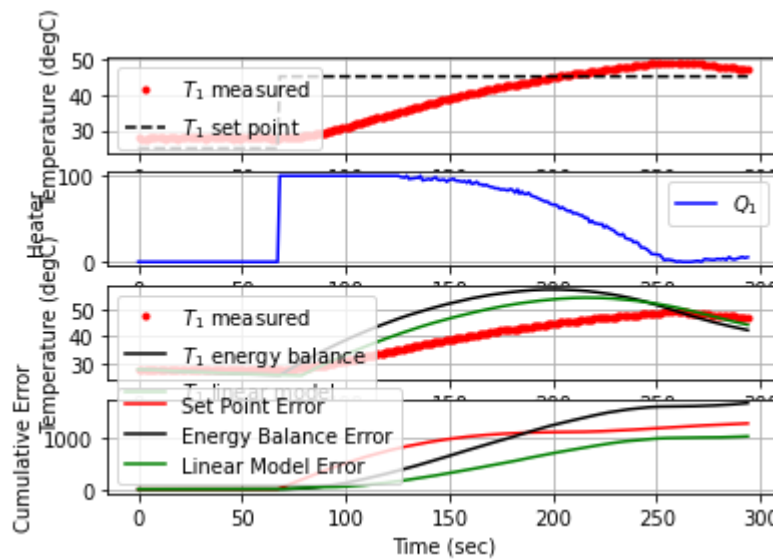
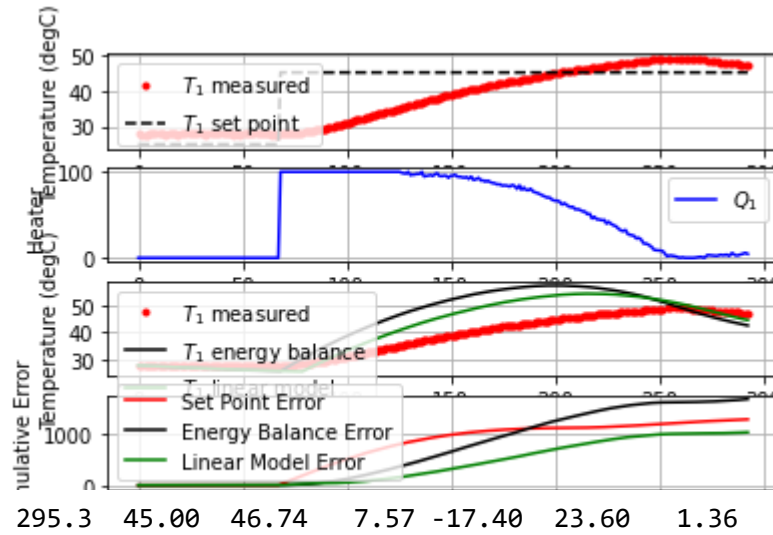


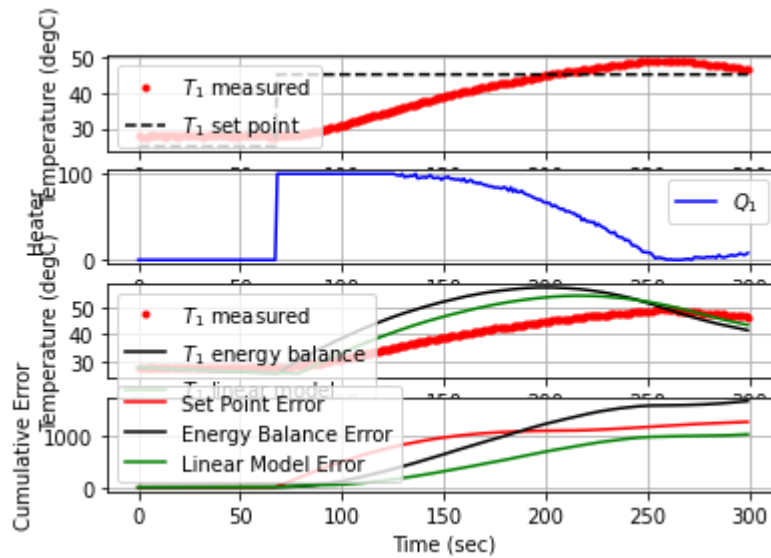
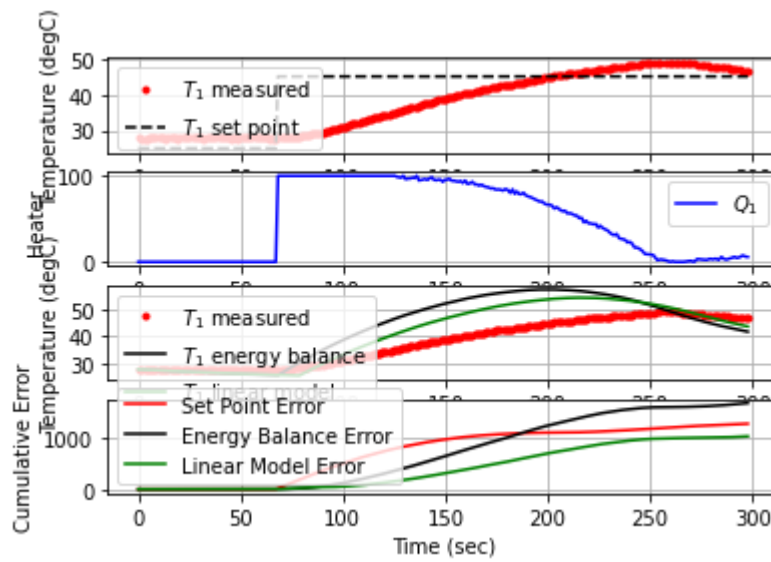
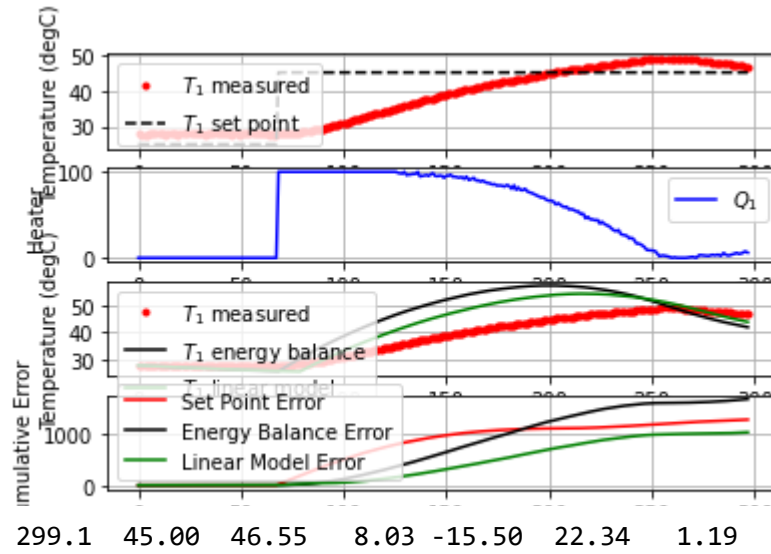


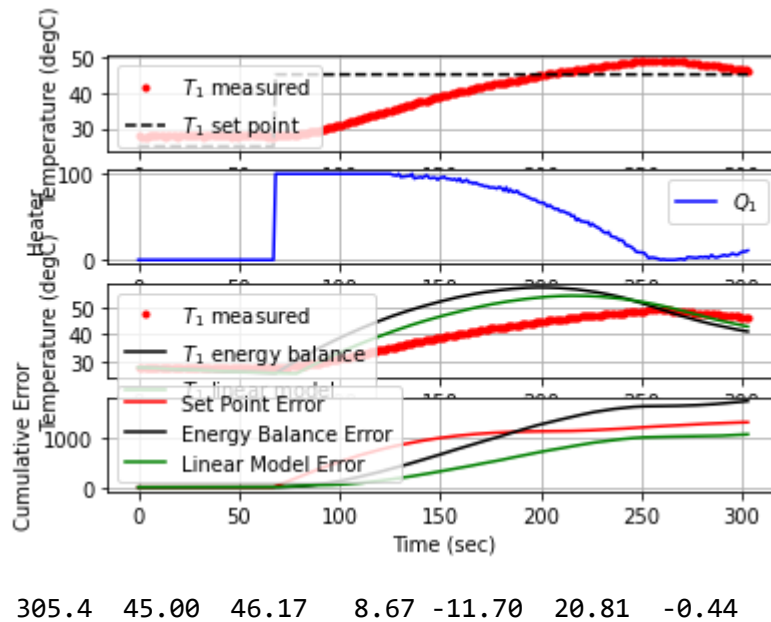
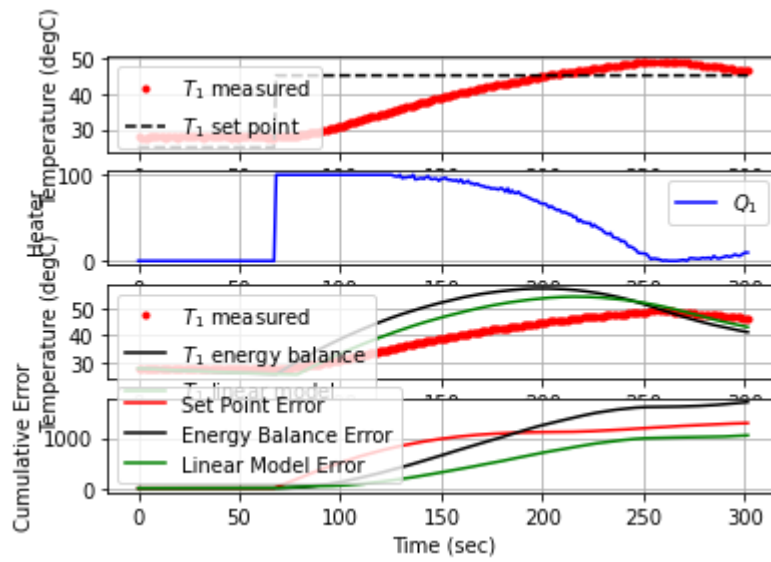
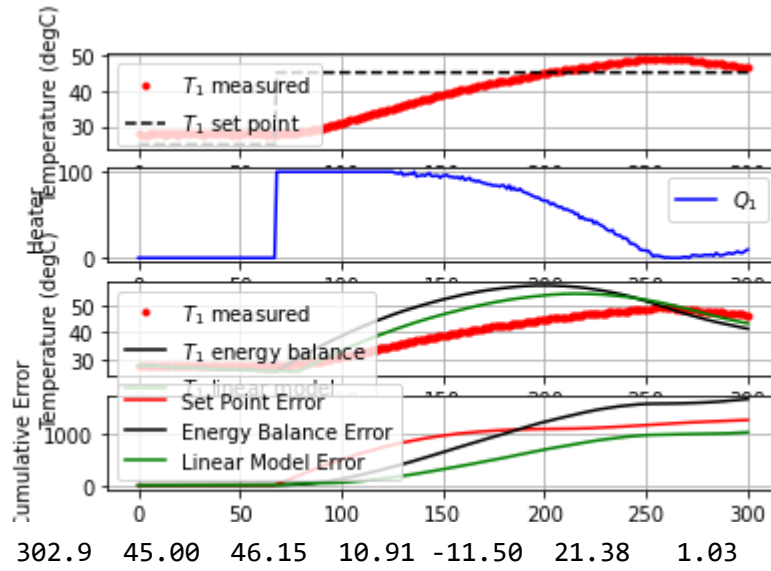


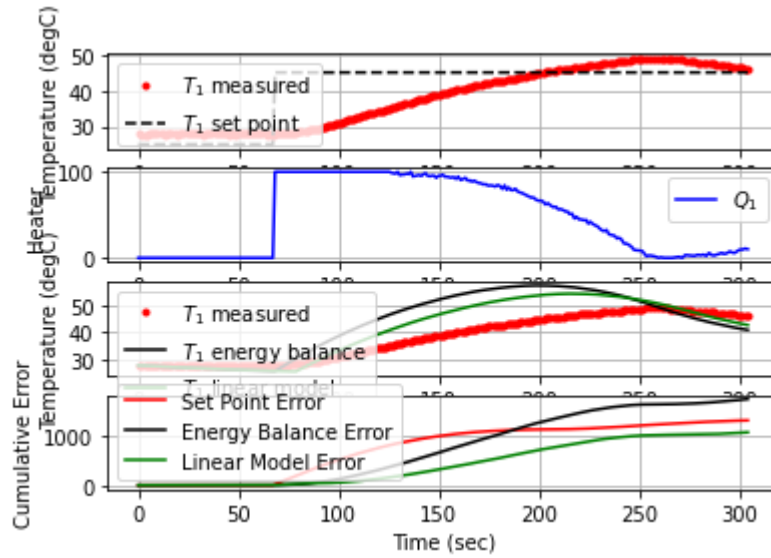




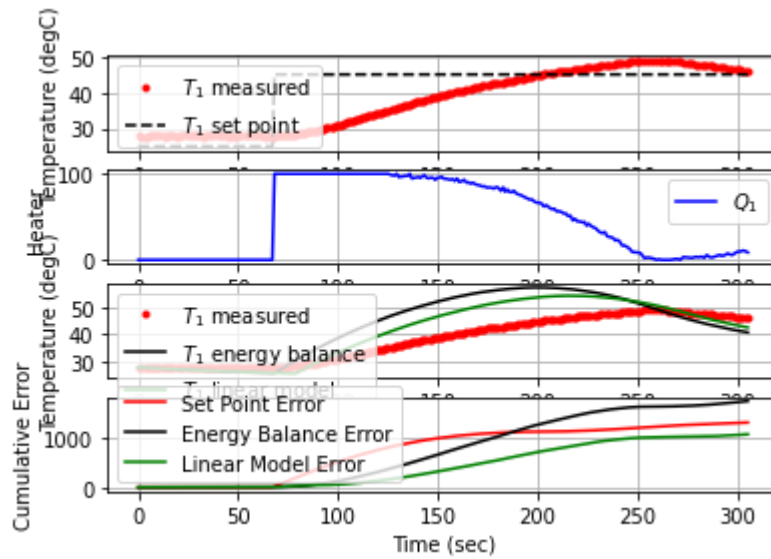




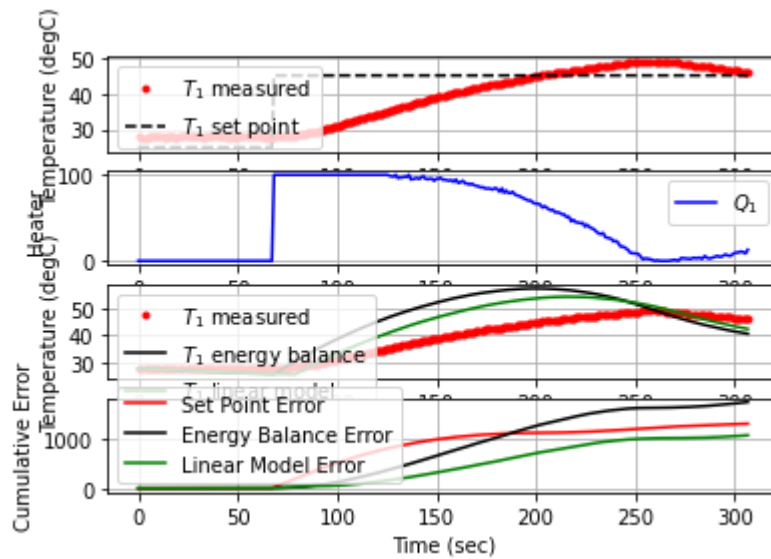




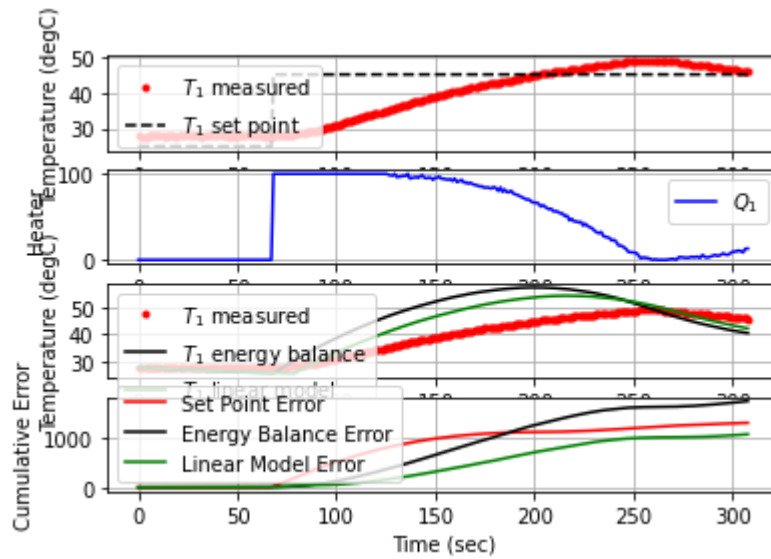
306.5 45.00 45.96 12.89 -9.60 20.60 1.90



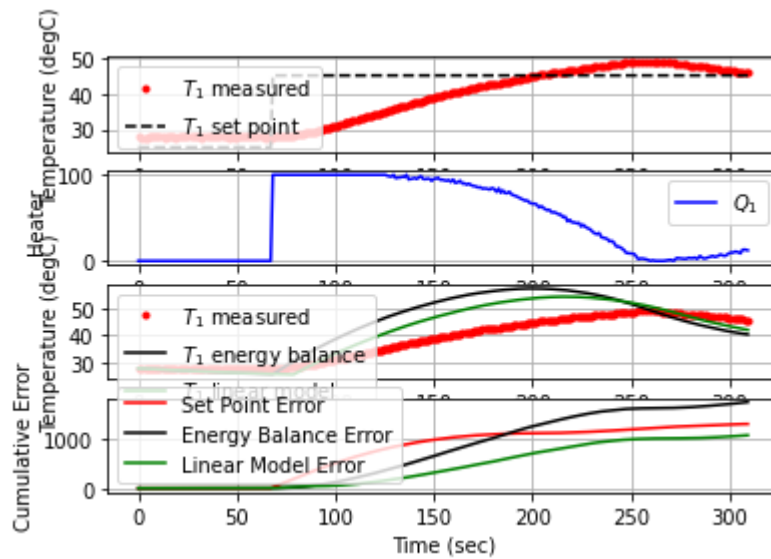
307.7 45.00 45.83 13.14 -8.30 20.39 1.04



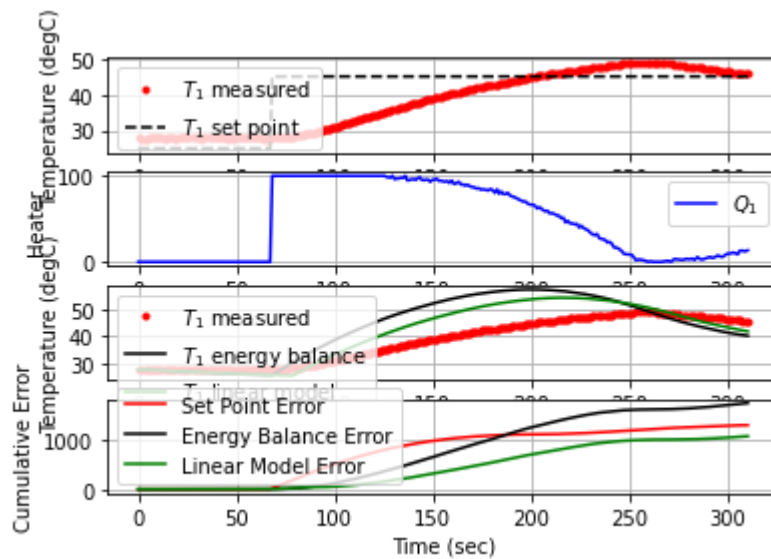
309.1 45.00 45.81 12.21 -8.10 20.17 0.14

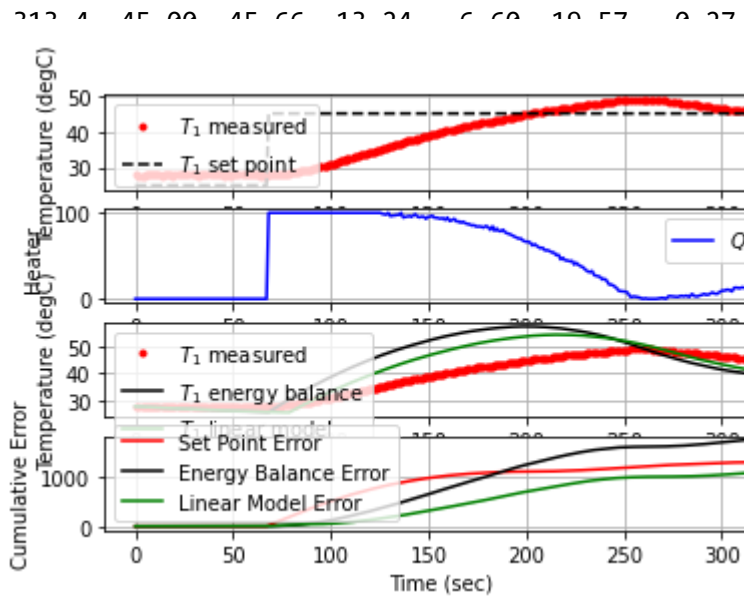


310.5 45.00 45.72 13.39 -7.20 19.96 0.63

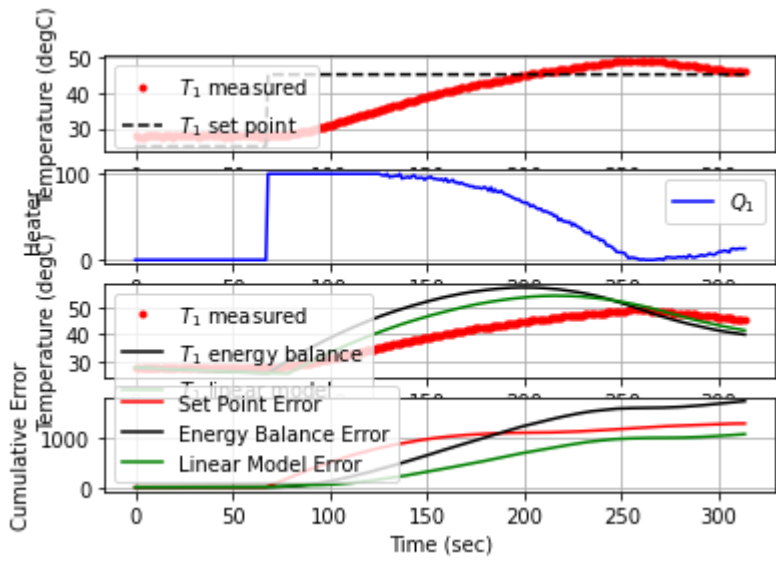


311.9 45.00 45.70 12.92 -7.00 19.77 0.15

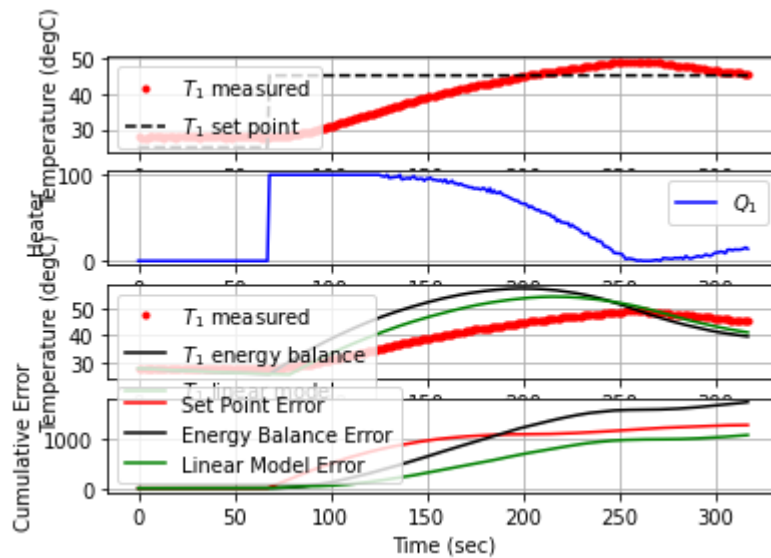
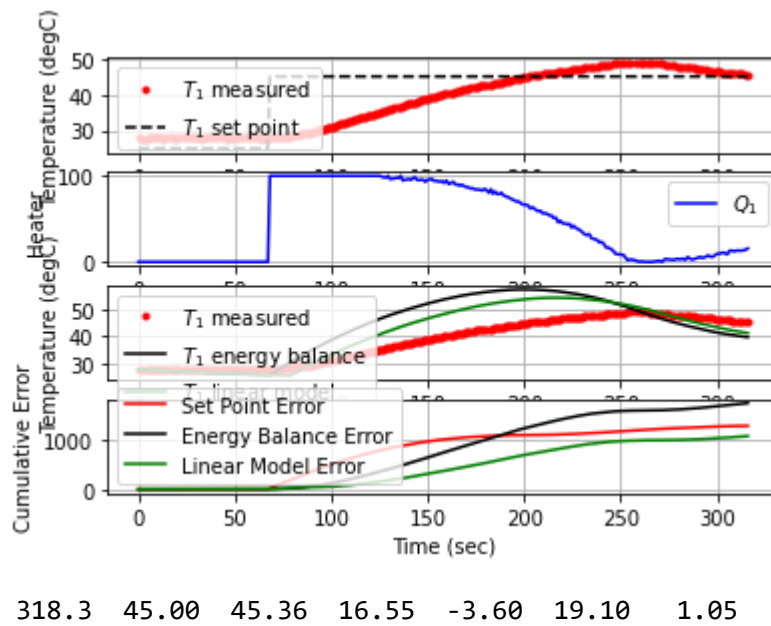
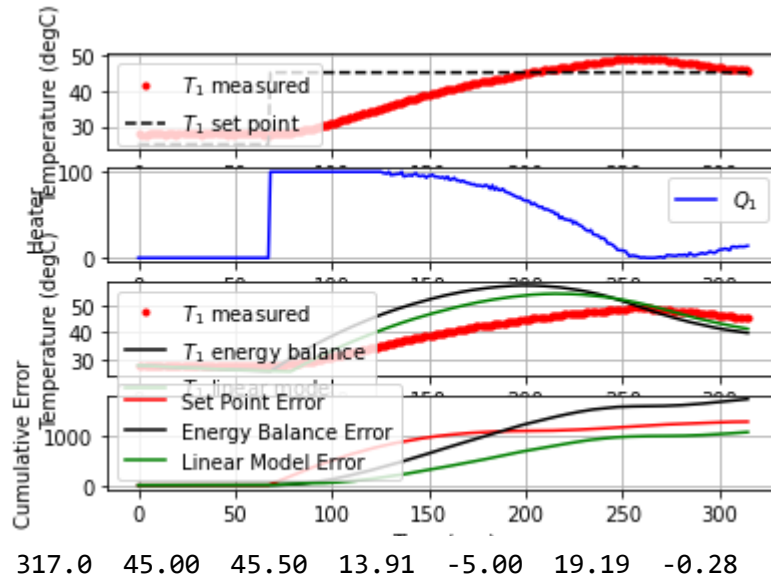




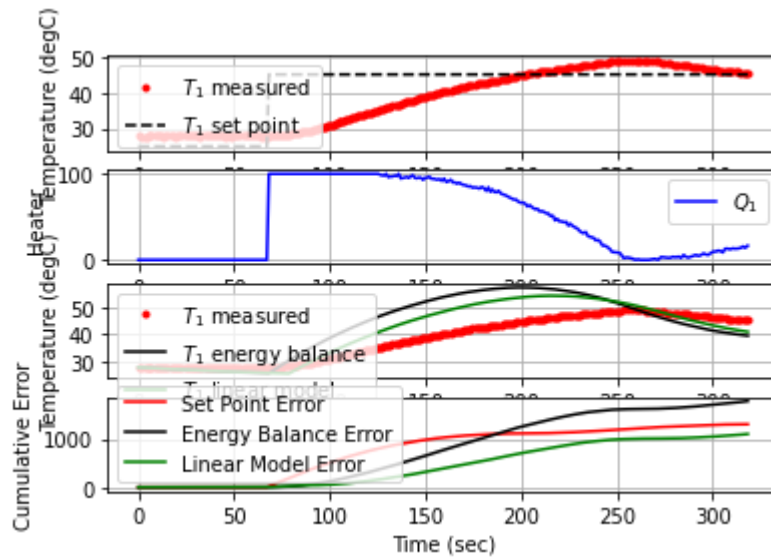
314.7 45.00 45.59 14.02 -5.90 19.41 0.51



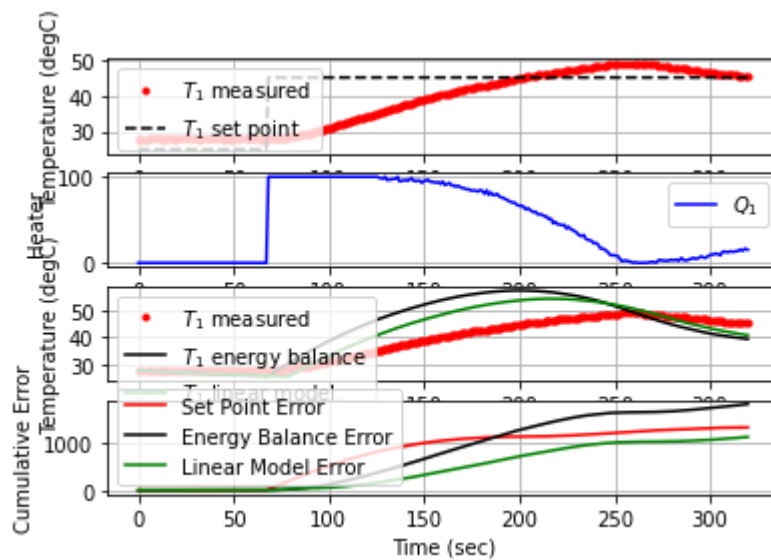
315.9 45.00 45.47 15.61 -4.70 19.30 1.01



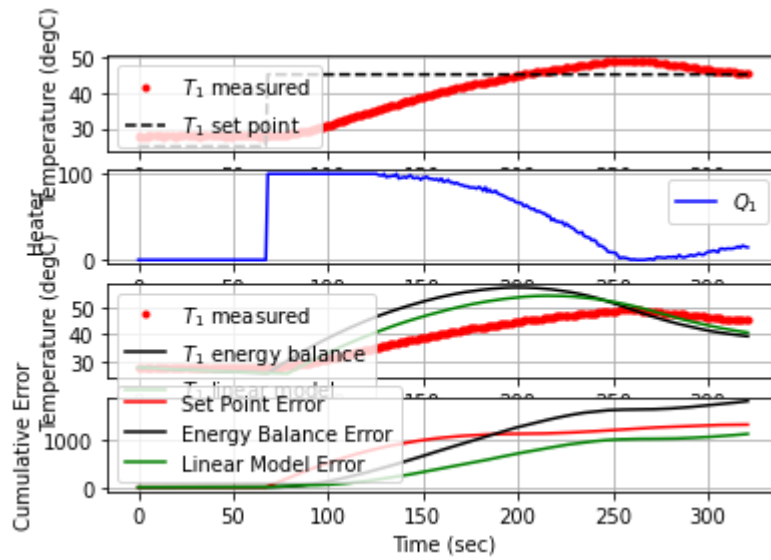
319.7 45.00 45.37 15.22 -3.70 18.99 -0.07



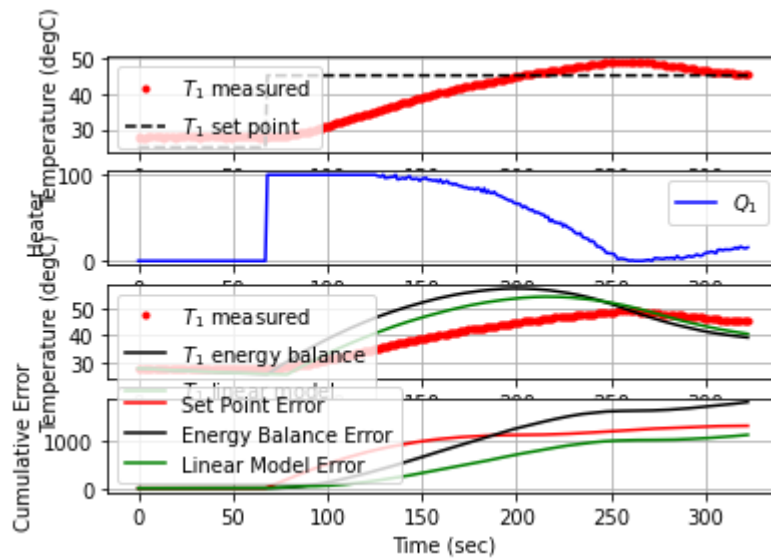
321.0 45.00 45.41 14.48 -4.10 18.89 -0.31



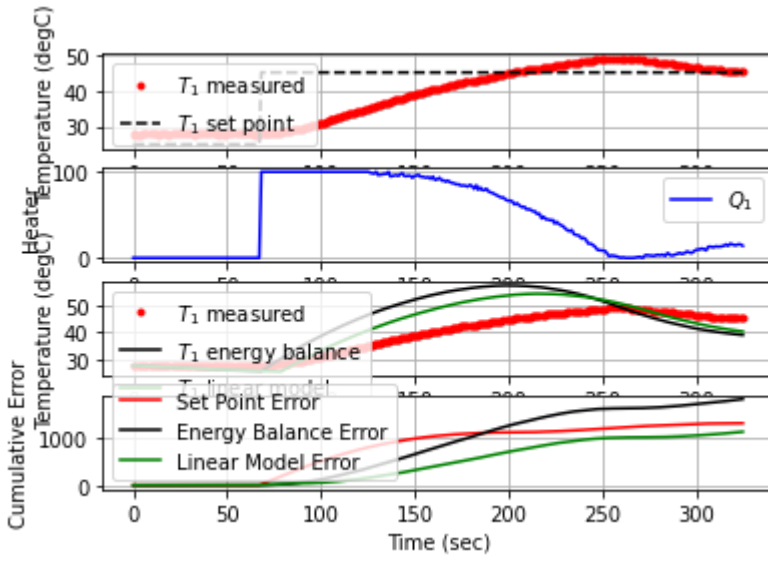
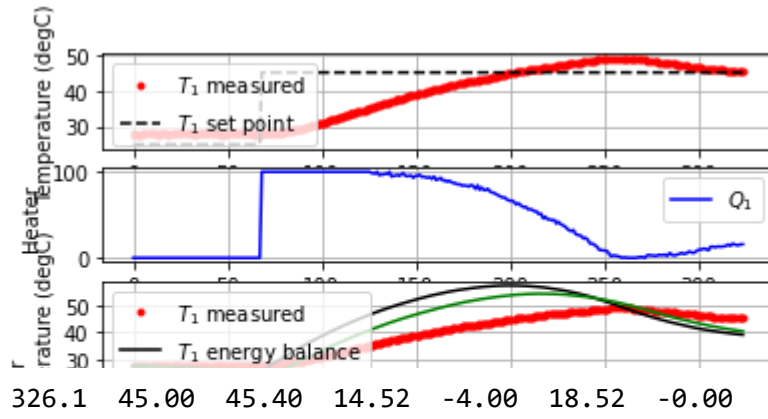
322.2 45.00 45.36 15.63 -3.60 18.80 0.43



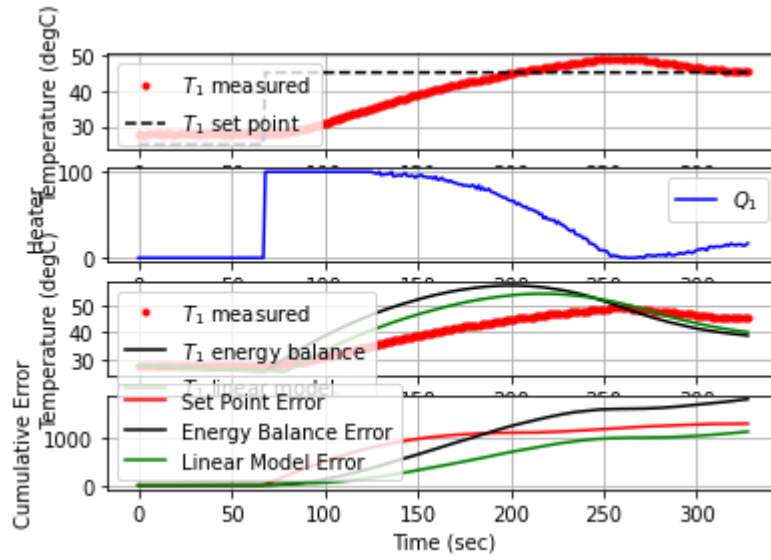
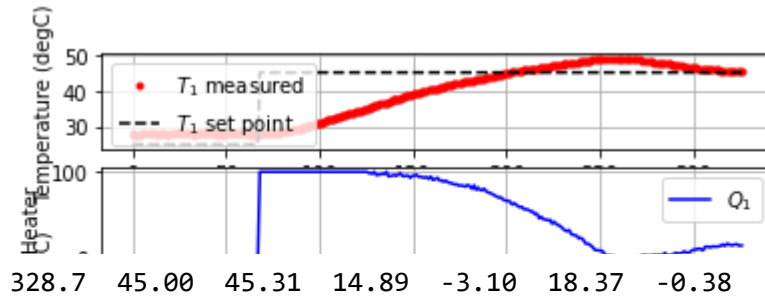
323.6 45.00 45.32 15.80 -3.20 18.71 0.29



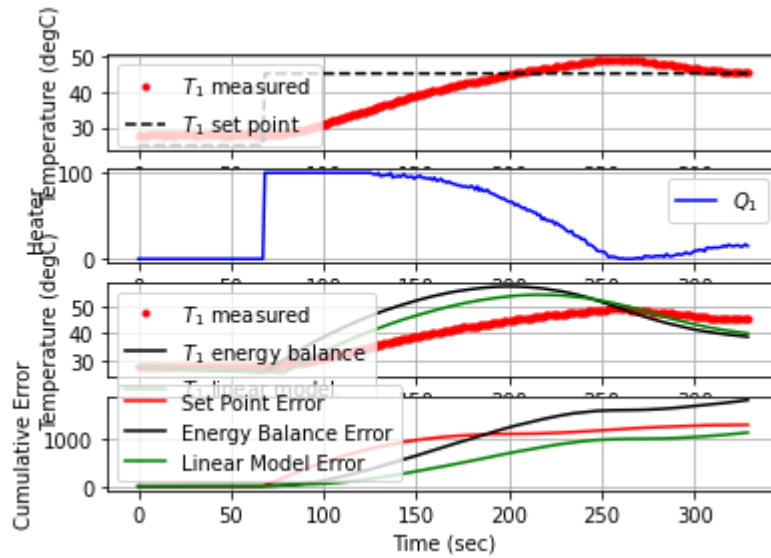
324.9 45.00 45.40 13.98 -4.00 18.61 -0.63



327.3 45.00 45.26 16.96 -2.60 18.45 1.11



329.9 45.00 45.20 17.22 -2.00 18.32 0.90




```
331.0 45.00 45.26 15.13 -2.60 18.26 -0.53  
Shutting down  
Arduino disconnected successfully  
Arduino disconnected successfully
```

Out[1]: True

<Figure size 432x288 with 0 Axes>

In [2]: a.close()

Arduino disconnected successfully

Out[2]: True

In []: