# WARM AND LIT SHOWER

# 10.008 PHYSICAL WORLD
# 1D REPORT


Tong Hui Kang
Wang Zihao
Yip Jun Han
Wu Tong

Singapore University of Technology and Design

23 March 2018

# Objective

We are integrating a LED temperature indicator in the shower water, so that users can shower safely in a comfortable temperature range.

## The current problem

In the shower, warm water is produced by mixing hot water and cold water. However, it is difficult for the user to adjust the right temperature in the shower, and the user spends a lot of time adjusting between water that is too hot and water that is too cold. Such a process wastes time, water and energy to make the water hot. Moreover, if the temperature is too hot, it might scald the user.

## Alternative solutions, and its limitations

An electric thermometer requires a change of batteries and could be easily corroded in the wet environment. The frequent replacement of its batteries and the device wastes resources. A liquid thermometer has a very small liquid column which makes it difficult for the user to read the temperature. Moreover, the liquid thermometer has to be placed very close to the source.
Therefore, an LED indicator saves resources and is highly visible.

# Application and motivation of your device

## The heat source used

Water has a high heat capacity, and heating water requires a significant amount of energy. We use the temperature difference between the mixed water and the cold water to power the indicator.
There is no opportunity cost in using this heat source. Assuming the modified shower head is equally insulated, whatever energy that is spent to heat up the water will be consumed by the user anyway. It is only a tiny amount of heat that is converted to work to power the LED. This heat would have travelled down the temperature anyway. Moreover, it is reasonable to integrate a pair of Peltier chips in the shower head, and extend an LED indicator.

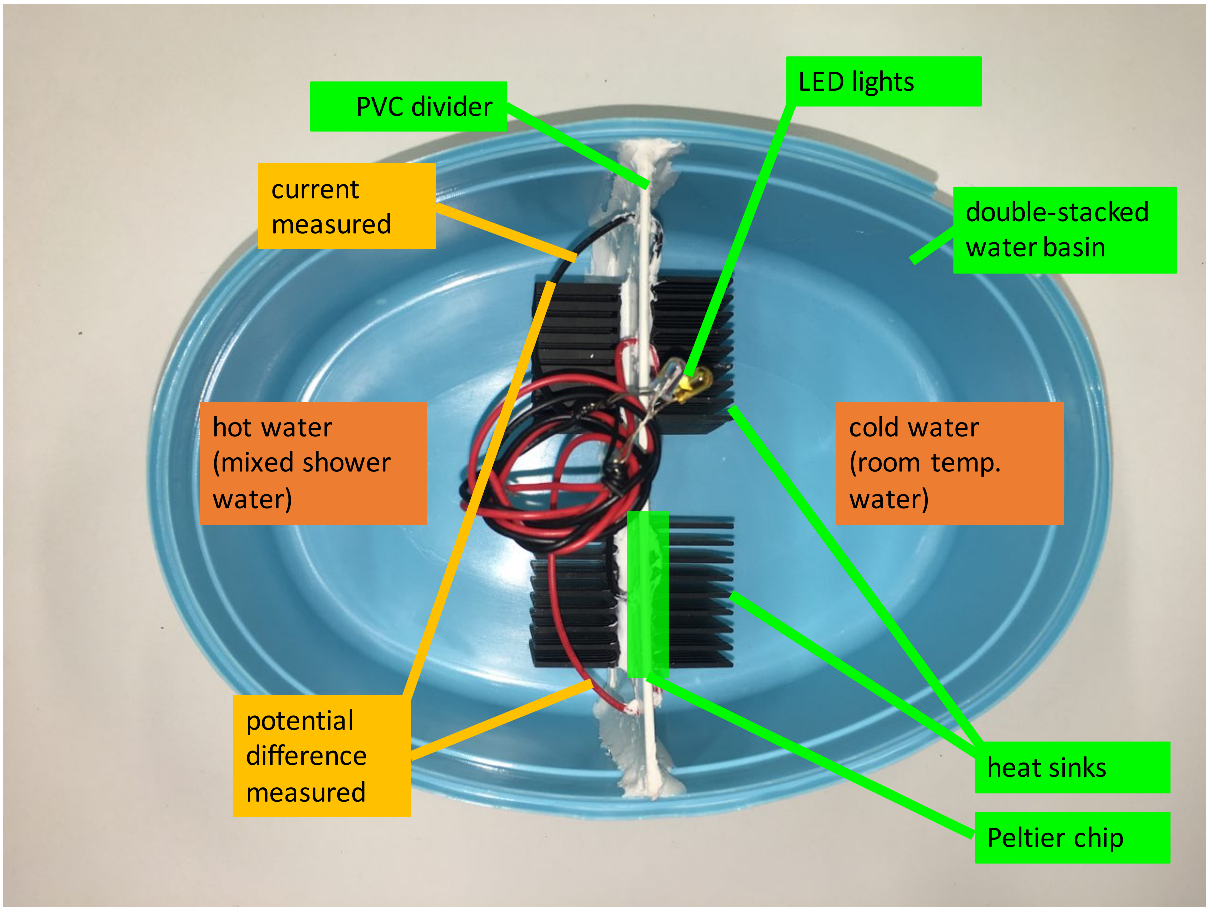
## Application powered

We are powering a pair of LED. Their lighting is indicative of the temperature. Breadboard LED lights do not require a high amount of current. Moreover, LED only lights up after the potential difference across the LED is higher than a certain specific value (1.8V to 3.3V, depending on the colour of the LED). We are using amber and blue LEDs which light up only when the potential difference is more than 2.2V and 2.4V respectively. Thus, LEDs are sensible considering the heat source we have chosen.

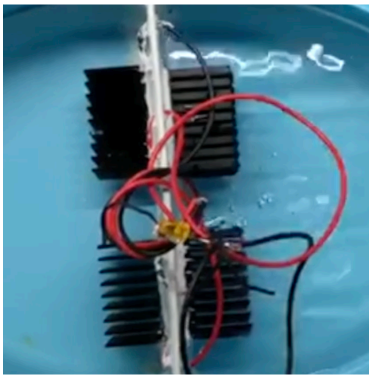
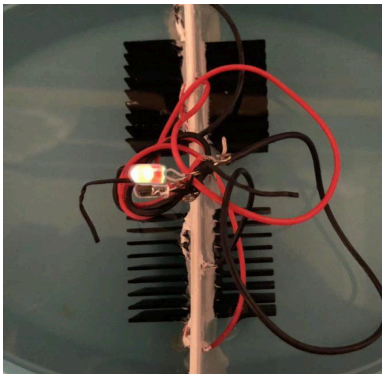
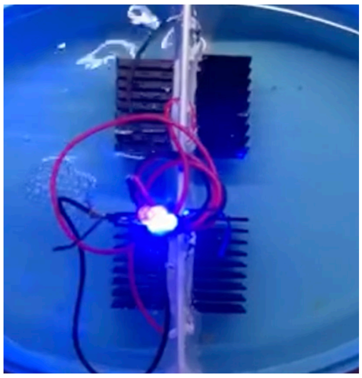
## Practicality of application

With this indicator, the user can get instant and safe feedback of the temperature of the water. However, the comfortable temperature range is different for different users, and the ambient temperature is different at different times. Nevertheless, the purpose of this prototype is to show a proof of concept. More LEDs with different voltage requirements can be used to more finely illustrate the temperature of the mixed shower water.

## Schematics diagram




These are our proposed outcomes for the shower temperature indicator, for respective temperature difference $T_d = T_h - T_c$

| Temperature of mixed shower water is:<br>Too cold | <br>Just right | <br>Too hot |
|---|---|---|
| $T_d < 10.3°C$<br>$V_o < 2.25V$<br> | $10.3°C < T_d < 12.2°C$<br>$2.25V < V_o < 2.44V$<br> | $T_d < 12.2°C$<br>$V_o < 2.44V$<br> |

# Results and Discussion

We filled up one side of the tub with hot water (80°C) and the other side of the tub with cool water (20°C). We used an infrared thermometer to measure the temperature of the water. To measure the power output, one multimeter was used to measure the potential difference across the LEDs and another multimeter was used to measure the current flowing through the LEDs. Measurements were made at fixed intervals of 15 seconds over ten minutes.

## Power input

The power input is estimated by the decrease in temperature of hot water over time, multiplied by with its mass (0.64kg) and heat capacity (4200J/kgK).

## Electrical power output

The electrical power output is estimated by the voltage across the external circuit and the current travelling through the external circuit.

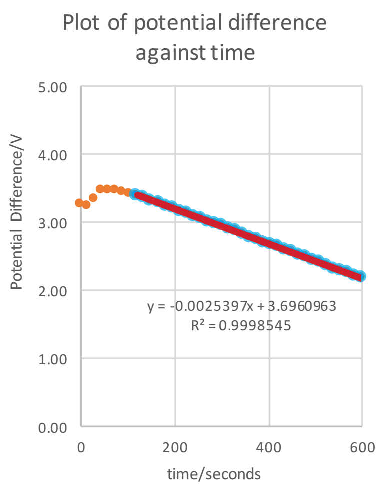
## Assumptions

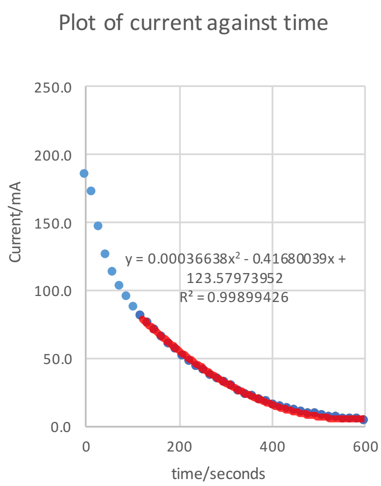
We assume that there is no heat loss through evaporation, conduction, convection or radiation to the surroundings. We also assume the PVC divider is a perfect insulator.

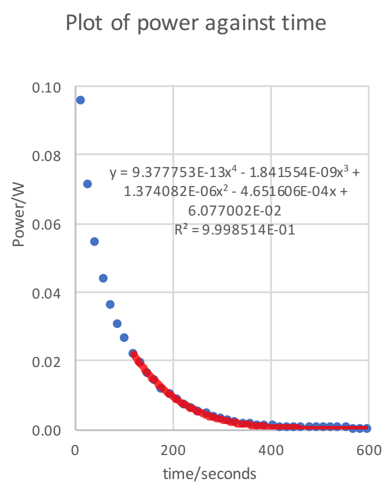
## The plot

The initial temperature, potential difference and current are not stable at the start. This is because the heat sink and the Peltier chip has yet to fully match the temperature of the water. To assume that the Peltier chip approximates a steady state, we will leave out the first two minutes of the measurements in our calculations. The first two minutes are inconsequential to our purpose because the LEDs do not require such a large temperature difference to function.

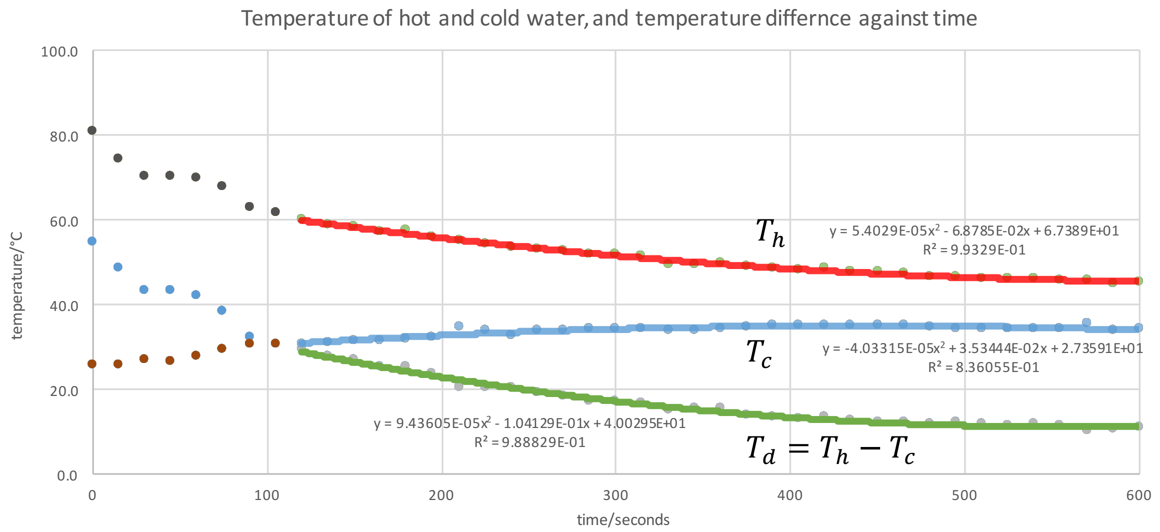
Following is the plot of potential difference and current over time. We calculate the power $P = I^2R$ output for each recorded time point.



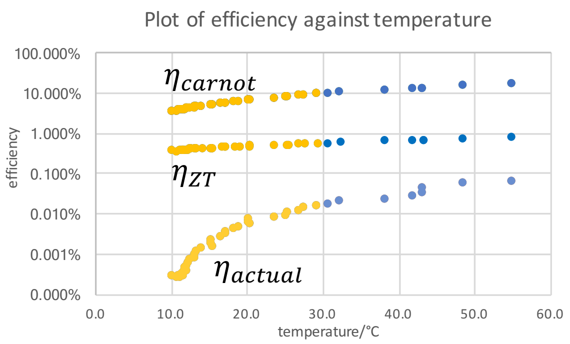



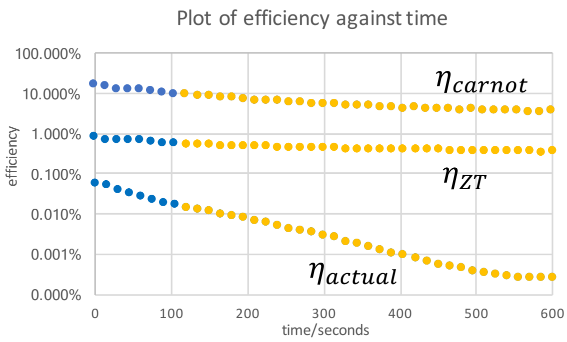



Following is the plot of the temperature of the hot and cold water, and the temperature difference against time. We model the trend of $T_h$ and $T_c$ with quadratic equations. $\dot{T}_h$ and $\dot{T}_c$ is estimated by differentiating the modeled $T_h$ and $T_c$ with respect to time, respectively.




Then $\dot{Q}_h$ and $\dot{Q}_c$ are calculated with the mass of water and the heat capacity of water. We then plot the actual efficiency $\eta = P/\dot{Q}_h$ for each recorded time point. Also included in the plot is the Carnot efficiency $\eta_{carnot} = 1 - (T_c/T_h)$ and maximum efficiency of the peltier chip $\eta_{ZT}$ ($S_e = 0.045VK^{-1},\ \lambda = 0.626WK^{-1},\ R_{IN} = 2.3\Omega,\ Z = 1.41 \cdot 10^{-3}$). The plot is in logarithmic scale because the values vary widely in magnitude. The full calculation details are in the attached appendix.




## Conclusion

We have conclusively shown the possibility of integrating a Peltier chip into the shower head to indicate the temperature of the shower water. The application is reasonable and has no opportunity cost outside of the setup cost.

### Youtube link to the video

[https://youtu.be/rD64HT4q0UM](https://youtu.be/rD64HT4q0UM)

| comments > | recorded | recorded | P = I^2 R | recorded | recorded | | LED status | mc(T-0°C) | mc(T-0°C) | d/dt(Q_h) | d/dt(Q_c) | P/Q_dot_h | 1-(T_c/T_h) | eqn | eqn | heat loss |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| t/sec | V/V | I/mA | P/W | T_h/°C | T_c/°C | T_h-T_c/°C | remarks | Q_h/J | Q_c/J | Q_dot_h/W | Q_dot_c/W | actual_eff | eff_max | ZT | eff_(ZT) | Q_surr/W |
| 0 | 3.25 | 184.1 | 1.102E-01 | 80.8 | 25.8 | 55.0 | | 217190.4 | 69350.4 | 184.894 | 95.006 | 0.059576% | 15.54% | 0.075 | 0.799% | 89.778 |
| 15 | 3.22 | 172.1 | 9.537E-02 | 74.3 | 25.7 | 48.6 | | 199718.4 | 69081.6 | 180.537 | 91.753 | 0.052826% | 13.99% | 0.071 | 0.704% | 88.688 |
| 30 | 3.34 | 145.6 | 7.081E-02 | 70.5 | 27.1 | 43.4 | | 189504.0 | 72844.8 | 176.180 | 88.501 | 0.040189% | 12.63% | 0.069 | 0.658% | 87.608 |
| 45 | 3.45 | 125.1 | 5.399E-02 | 70.2 | 26.8 | 43.4 | | 188697.6 | 72038.4 | 171.823 | 85.249 | 0.031423% | 12.64% | 0.068 | 0.652% | 86.521 |
| 60 | 3.46 | 112.1 | 4.348E-02 | 69.9 | 27.9 | 42.0 | | 187891.2 | 74995.2 | 167.466 | 81.996 | 0.025963% | 12.24% | 0.069 | 0.654% | 85.427 |
| 75 | 3.46 | 102.1 | 3.607E-02 | 67.7 | 29.4 | 38.3 | | 181977.6 | 79027.2 | 163.110 | 78.744 | 0.022113% | 11.24% | 0.068 | 0.631% | 84.329 |
| 90 | 3.44 | 94.1 | 3.046E-02 | 63.1 | 30.7 | 32.4 | | 169612.8 | 82521.6 | 158.753 | 75.492 | 0.019187% | 9.64% | 0.066 | 0.574% | 83.230 |
| 105 | 3.42 | 87.3 | 2.606E-02 | 61.7 | 30.9 | 30.8 | | 165849.6 | 83059.2 | 154.396 | 72.239 | 0.016882% | 9.20% | 0.065 | 0.556% | 82.130 |
| 120 | 3.39 | 80.0 | 2.170E-02 | 60.2 | 30.8 | 29.4 | | 161817.6 | 82790.4 | 150.039 | 68.987 | 0.014460% | 8.82% | 0.064 | 0.536% | 81.030 |
| 135 | 3.36 | 75.1 | 1.895E-02 | 58.9 | 31.2 | 27.7 | | 158323.2 | 83865.6 | 145.682 | 65.735 | 0.013008% | 8.34% | 0.064 | 0.520% | 79.928 |
| 150 | 3.31 | 69.9 | 1.617E-02 | 58.6 | 31.6 | 27.0 | | 157516.8 | 84940.8 | 141.325 | 62.482 | 0.011444% | 8.14% | 0.064 | 0.518% | 78.826 |
| 165 | 3.28 | 65.0 | 1.386E-02 | 57.2 | 31.6 | 25.6 | | 153753.6 | 84940.8 | 136.968 | 59.230 | 0.010118% | 7.75% | 0.063 | 0.499% | 77.724 |
| 180 | 3.24 | 60.0 | 1.166E-02 | 57.5 | 32.1 | 25.4 | | 154560.0 | 86284.8 | 132.611 | 55.978 | 0.008796% | 7.68% | 0.063 | 0.505% | 76.622 |
| 195 | 3.20 | 56.1 | 1.007E-02 | 56.1 | 32.3 | 23.8 | | 150796.8 | 86822.4 | 128.254 | 52.725 | 0.007852% | 7.23% | 0.062 | 0.488% | 75.519 |
| 210 | 3.16 | 51.5 | 8.381E-03 | 55.4 | 35.0 | 20.4 | | 148915.2 | 94080.0 | 123.898 | 49.473 | 0.006765% | 6.21% | 0.064 | 0.487% | 74.416 |
| 225 | 3.12 | 47.5 | 7.040E-03 | 54.4 | 34.0 | 20.4 | | 146227.2 | 91392.0 | 119.541 | 46.221 | 0.005889% | 6.23% | 0.062 | 0.471% | 73.313 |
| 240 | 3.08 | 43.5 | 5.828E-03 | 53.4 | 32.9 | 20.5 | | 143539.2 | 88435.2 | 115.184 | 42.968 | 0.005060% | 6.28% | 0.061 | 0.455% | 72.209 |
| 255 | 3.04 | 40.0 | 4.864E-03 | 53.0 | 33.8 | 19.2 | | 142464.0 | 90854.4 | 110.827 | 39.716 | 0.004389% | 5.89% | 0.061 | 0.452% | 71.106 |
| 270 | 3.01 | 37.2 | 4.165E-03 | 52.7 | 34.2 | 18.5 | | 141657.6 | 91929.6 | 106.470 | 36.464 | 0.003912% | 5.68% | 0.061 | 0.449% | 70.002 |
| 285 | 2.98 | 34.2 | 3.486E-03 | 51.9 | 34.6 | 17.3 | | 139507.2 | 93004.8 | 102.113 | 33.211 | 0.003413% | 5.32% | 0.061 | 0.440% | 68.898 |
| 300 | 2.94 | 31.7 | 2.954E-03 | 51.8 | 34.5 | 17.3 | | 139238.4 | 92736.0 | 97.756 | 29.959 | 0.003022% | 5.32% | 0.061 | 0.438% | 67.794 |
| 315 | 2.90 | 28.6 | 2.372E-03 | 51.4 | 34.6 | 16.8 | | 138163.2 | 93004.8 | 93.399 | 26.707 | 0.002540% | 5.18% | 0.061 | 0.433% | 66.690 |
| 330 | 2.86 | 25.2 | 1.816E-03 | 49.6 | 34.2 | 15.4 | | 133324.8 | 91929.6 | 89.042 | 23.454 | 0.002040% | 4.77% | 0.059 | 0.409% | 65.586 |
| 345 | 2.82 | 23.1 | 1.505E-03 | 49.6 | 34.1 | 15.5 | | 133324.8 | 91660.8 | 84.685 | 20.202 | 0.001777% | 4.80% | 0.059 | 0.409% | 64.482 |
| 360 | 2.78 | 20.7 | 1.191E-03 | 50.1 | 34.5 | 15.6 | | 134668.8 | 92736.0 | 80.329 | 16.950 | 0.001483% | 4.83% | 0.060 | 0.416% | 63.378 |
| 375 | 2.74 | 18.7 | 9.582E-04 | 49.1 | 34.9 | 14.2 | | 131980.8 | 93811.2 | 75.972 | 13.697 | 0.001261% | 4.41% | 0.059 | 0.404% | 62.273 |
| 390 | 2.70 | 16.9 | 7.711E-04 | 48.7 | 35.2 | 13.5 | | 130905.6 | 94617.6 | 71.615 | 10.445 | 0.001077% | 4.19% | 0.059 | 0.399% | 61.169 |
| 405 | 2.67 | 15.2 | 6.169E-04 | 48.4 | 35.1 | 13.3 | | 130099.2 | 94348.8 | 67.258 | 7.193 | 0.000917% | 4.14% | 0.059 | 0.395% | 60.064 |
| 420 | 2.63 | 13.5 | 4.793E-04 | 48.6 | 35.2 | 13.4 | | 130636.8 | 94617.6 | 62.901 | 3.940 | 0.000762% | 4.16% | 0.059 | 0.398% | 58.960 |
| 435 | 2.60 | 12.3 | 3.934E-04 | 48.0 | 35.3 | 12.7 | | 129024.0 | 94886.4 | 58.544 | 0.688 | 0.000672% | 3.95% | 0.059 | 0.390% | 57.856 |
| 450 | 2.56 | 10.9 | 3.042E-04 | 47.8 | 35.3 | 12.5 | | 128486.4 | 94886.4 | 54.187 | -2.564 | 0.000561% | 3.89% | 0.059 | 0.387% | 56.751 |
| 465 | 2.52 | 9.8 | 2.420E-04 | 47.5 | 35.2 | 12.3 | | 127680.0 | 94617.6 | 49.830 | -5.817 | 0.000486% | 3.84% | 0.058 | 0.383% | 55.647 |
| 480 | 2.48 | 8.9 | 1.964E-04 | 46.8 | 34.8 | 12.0 | | 125798.4 | 93542.4 | 45.473 | -9.069 | 0.000432% | 3.75% | 0.058 | 0.374% | 54.542 |
| 495 | 2.44 | 7.9 | 1.523E-04 | 46.7 | 34.5 | 12.2 | blue off | 125529.6 | 92736.0 | 41.116 | -12.321 | 0.000370% | 3.81% | 0.057 | 0.372% | 53.437 |
| 510 | 2.40 | 7.1 | 1.210E-04 | 46.3 | 34.5 | 11.8 | | 124454.4 | 92736.0 | 36.760 | -15.574 | 0.000329% | 3.69% | 0.057 | 0.367% | 52.333 |
| 525 | 2.36 | 6.4 | 9.667E-05 | 46.1 | 34.4 | 11.7 | | 123916.8 | 92467.2 | 32.403 | -18.826 | 0.000298% | 3.66% | 0.057 | 0.364% | 51.228 |
| 540 | 2.32 | 5.7 | 7.538E-05 | 46.1 | 34.3 | 11.8 | | 123916.8 | 92198.4 | 28.046 | -22.078 | 0.000269% | 3.70% | 0.057 | 0.364% | 50.124 |
| 555 | 2.28 | 5.1 | 5.930E-05 | 45.9 | 34.5 | 11.4 | | 123379.2 | 92736.0 | 23.689 | -25.331 | 0.000250% | 3.57% | 0.057 | 0.361% | 49.019 |
| 570 | 2.25 | 4.7 | 4.970E-05 | 45.8 | 35.5 | 10.3 | amber off | 123110.4 | 95424.0 | 19.332 | -28.583 | 0.000257% | 3.23% | 0.057 | 0.360% | 47.915 |
| 585 | 2.21 | 4.1 | 3.715E-05 | 45.0 | 34.1 | 10.9 | | 120960.0 | 91660.8 | 14.975 | -31.835 | 0.000248% | 3.43% | 0.056 | 0.349% | 46.810 |
| 600 | 2.17 | 3.6 | 2.812E-05 | 45.5 | 34.3 | 11.2 | | 122304.0 | 92198.4 | 10.618 | -35.088 | 0.000265% | 3.51% | 0.056 | 0.356% | 45.706 |