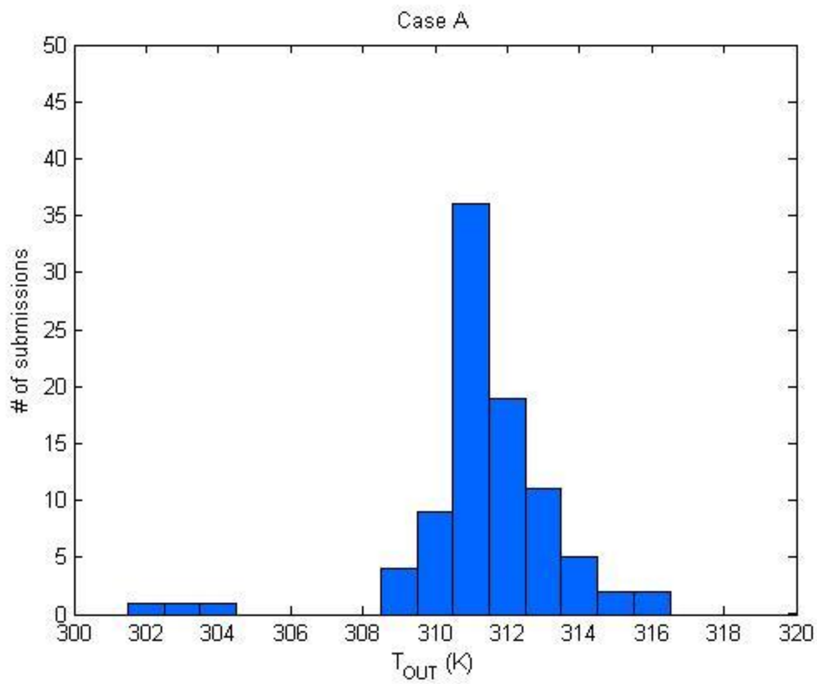
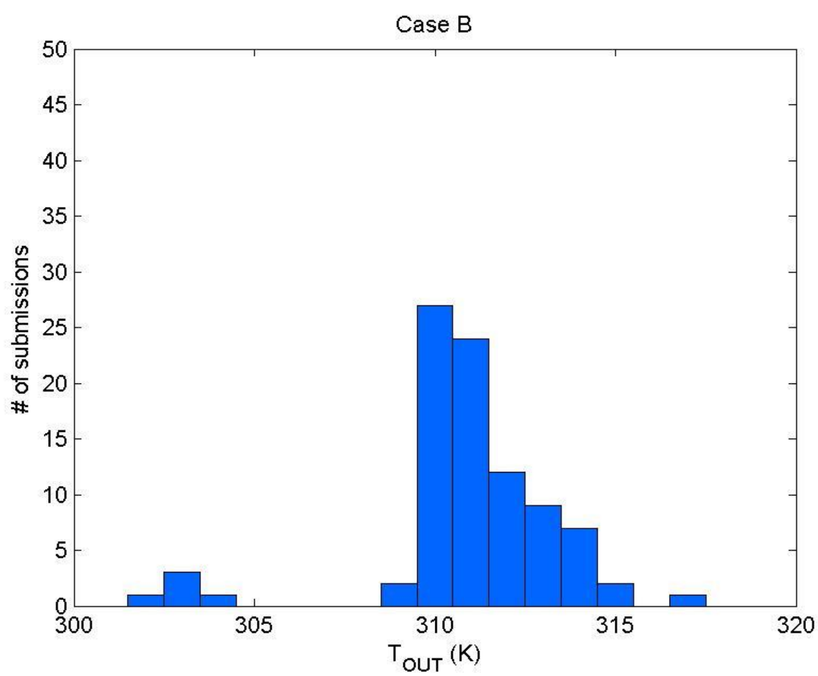
Statistics of T_out from the submissions of Project #1

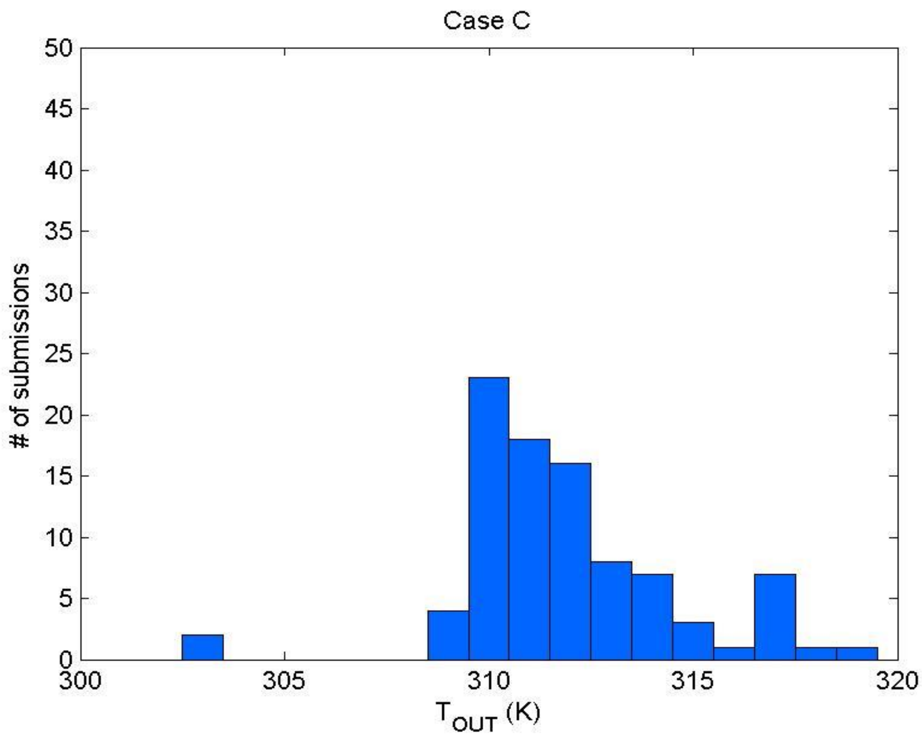
Case A



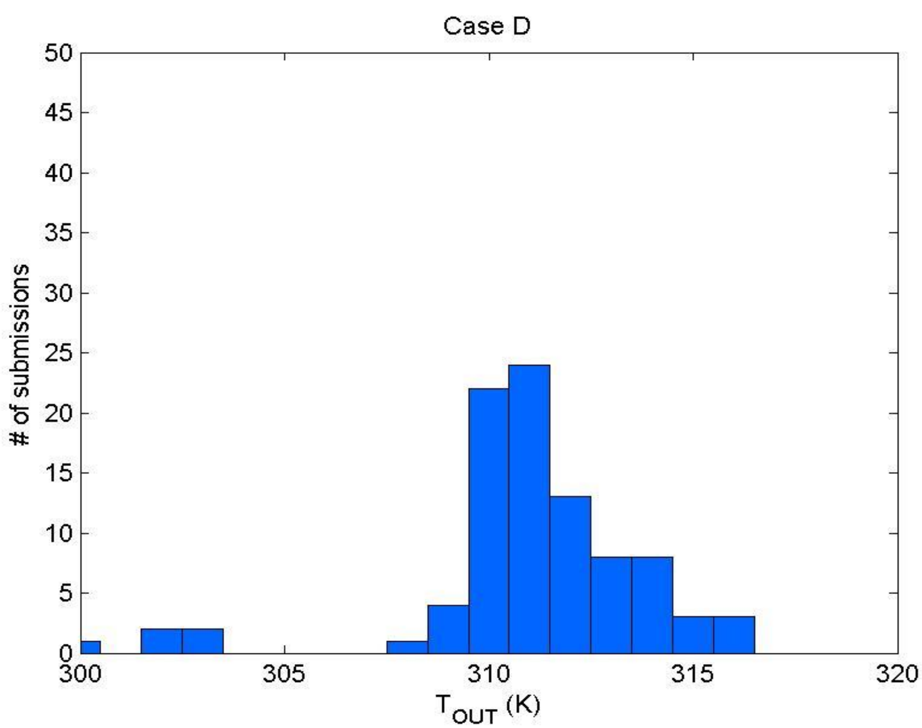
Case B



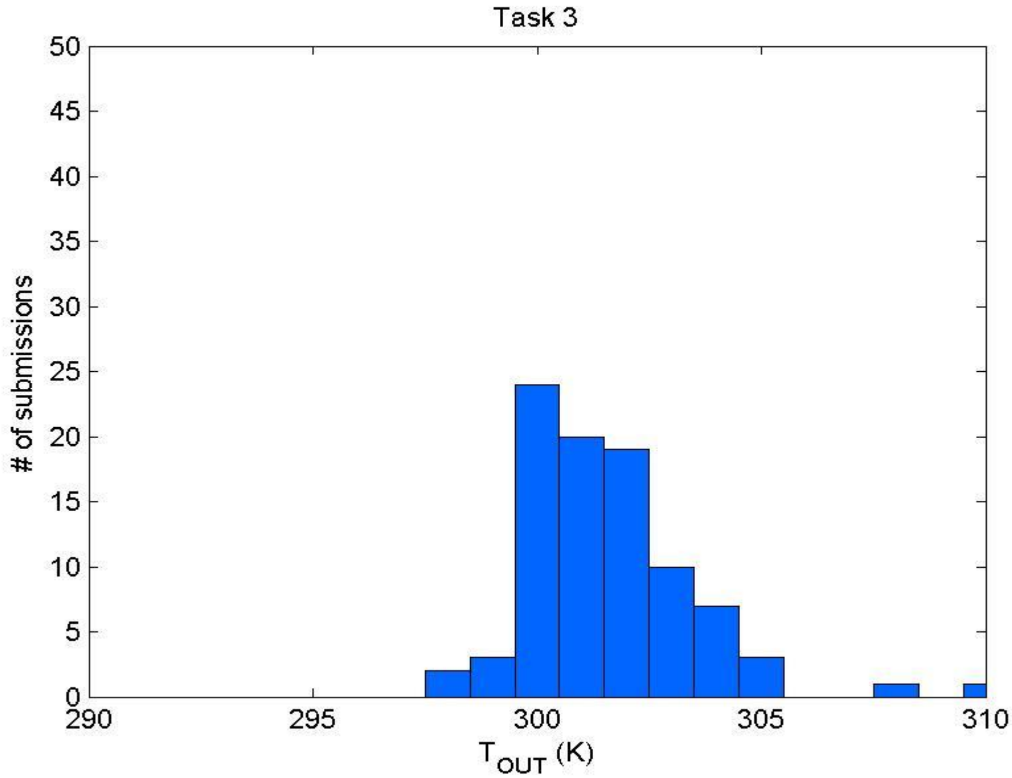
Case C


Case C
# of submissions
50
45
40
35
30
25
20
15
10
5
0
300
305
310
315
320
T_{OUT} (K)

Case D


Case D
# of submissions
50
45
40
35
30
25
20
15
10
5
0
300
305
310
315
320
T_{OUT} (K)

Task 3 (constant density)



Remarks:

The four cases, A-D, are very close. The means of the four cases are in the range of 311-312 K while the differences among them are not statistically significant. The variation of the results within the same case is due to the choices of mesh resolution and number of iteration, among other parameters. We had intentionally allowed flexibility in the selections of those parameters (or else the project would have been just another tutorial). Had those parameters been strictly specified in the handout, we would expect a narrower range of the outcome for each case (such that a clear order of the four cases might also emerge). Overall, this demonstrates the impact of mesh refinement and numerical scheme/procedure on the solution of this task.

The relative insensitivity of the outcome of the four cases on the geometry of the tank is not unexpected since (i) The water tank is small which allows quick, thorough mixing, (ii) The area of the hot bottom plate and the total volume of the main tank are the same for all 4 cases.

Compared to case A, the distributions of T_out for cases B-D are skewed more towards a higher value. This could possibly be attributed to the lower position of the inlet for cases B-D. This allows cold water to more easily reach the bottom and help maintain a strong vertical temperature gradient (which is critical for heat transfer from the bottom plate into the tank). Nevertheless, the outcome of the numerical simulations indicate that this effect is relatively minor.

While the results for cases A-D are generally close, the case in Task 3 (with constant density) produces a significantly lower T_out, by around 10C, compared to the original case with varying density. This shows that the inclusion of buoyancy effect by switching to “Boussinesq” has a major impact on the outcome.

Lastly, in Task 4 (with imposed heat flux), the T_out should be very close to its counterpart with imposed temperature. This is expected just by a simple argument of energy balance.

Challenge #1:

The majority of the submissions with the correct setup of UDF produced a T_out at 305-306 K, or about 5 degrees lower than the original task with a uniform 65C temperature at bottom. This reduction of T_out is expected, since in the new case the temperature at bottom plate is significantly lower.

Challenge #2:

The temperatures at the outlet and in the middle of the tank increase with a decreasing inlet velocity. This is because with a lower velocity water tends to stay in the tank longer, allowing a longer time for it to get heated up before exiting the tank.

Some submissions showed not a monotonic decreasing trend of T_out (or T_mid) with an increasing V_inlet but a fluctuating or "zigzag" pattern. This could be due to (i) Influence of backflow (which is more pronounced at low inlet velocity), (ii) Insufficient number of iteration, (iii) Numerical errors due to coarse mesh resolution, among other factors. Some students found that the issue with backflow can be alleviated by switching the outlet boundary condition from “pressure outlet” to “outflow”. (See a demonstration in the first reference solution.)