

EFFECT AND APPROPRIATE USE OF TIME_SHRINK_FACTOR IN FDS

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ABSTRACT

The Fire Dynamics Simulator (FDS), developed by the National Institute of Standards and Technology (NIST), is used frequently for various fire protection engineering applications. FDS uses Large Eddy Simulation (LES) techniques to solve the Low Mach Number form of the Navier-Stokes equations. It is used in a variety of fire protection designs where prescriptive requirements may not be applicable or feasible. Some of these applications are the analysis of smoke control systems, exterior building exposure, alternate materials, and/or alternate fuel load and/or arrangement.

One of the major limitations of FDS is that it requires significant computational time and capacity. With ever increasing complexity of the built environment, FDS simulations require numerous central processing units (CPU) and is typically run on a dedicated server. Even then, these simulations can take on the order of weeks to run. Within FDS, there is a command "TIME_SHRINK_FACTOR" which reduces the time necessary to transfer heat to surfaces by reducing the specific heat of the materials by that factor. The FDS user guide states that this can be used in steady-state applications and provides a reference for a simple steady-state case.

This research will focus on using this factor and analyze how it affects both the model results and run time simulations with regard to the applications listed above. The simulations will be run both with and without the factor. Wall temperature, air/smoke temperature, smoke movement, soot concentration, and incident heat flux will all be evaluated. The analysis will describe the similarities or differences of the results that the simulation with the factor produced, and assess the ability to use the factor properly. This research will summarize when the TIME_SHRINK_FACTOR is appropriate for fire protection design applications, its capabilities of reduced run time, and the limitations of its use.

TIME SHRINK FACTOR INTRODUCTION

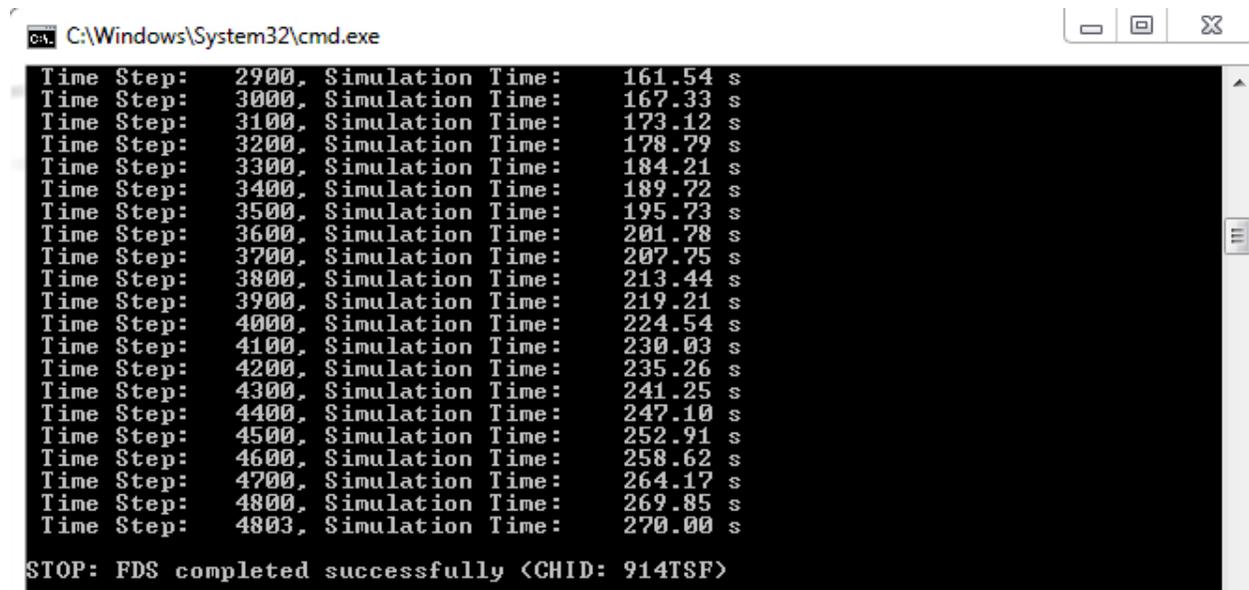
Within FDS, there is a command "TIME_SHRINK_FACTOR" which reduces the time necessary to transfer heat to surfaces by reducing the specific heat of the materials by that factor. The TIME_SHRINK_FACTOR can be introduced into an FDS file by using the following line of code:

```
&TIME TIME_SHRINK_FACTOR=10./
```

For the code above, the factor is noted as 10, which would then reduce the specific heats of the materials within FDS by a factor of 10, speeding up the heating of these materials roughly by 10. Therefore the computing time needed to calculate the heat transfer would in turn be reduced.

The FDS user guide also provides the following information on device activation. Note that when TIME_SHRINK_FACTOR is used with a device QUANTITY='TIME' or a device or control function with a DELAY will have those values adjusted by the value of TIME_SHRINK_FACTOR. For example, if a 10 s DELAY is specified for a CTRL input with a TIME_SHRINK_FACTOR of 10, then FDS will ADJUST the DELAY to 1 second.

Additionally, while the simulation is running one will notice within the command window that the simulation time will also be shortened by the TIME_SHRINK_FACTOR. In this scenario above with a TIME_SHRINK_FACTOR of 10, an original simulation time of 2700 seconds would be reduced to 270 seconds. When the results are viewed within smokeview, the simulation time will show as normal. The following two images (Figure 1 and Figure 2) are from the same simulation and show the resulting two simulation times.



```
C:\Windows\System32\cmd.exe
Time Step: 2900, Simulation Time: 161.54 s
Time Step: 3000, Simulation Time: 167.33 s
Time Step: 3100, Simulation Time: 173.12 s
Time Step: 3200, Simulation Time: 178.79 s
Time Step: 3300, Simulation Time: 184.21 s
Time Step: 3400, Simulation Time: 189.72 s
Time Step: 3500, Simulation Time: 195.73 s
Time Step: 3600, Simulation Time: 201.78 s
Time Step: 3700, Simulation Time: 207.75 s
Time Step: 3800, Simulation Time: 213.44 s
Time Step: 3900, Simulation Time: 219.21 s
Time Step: 4000, Simulation Time: 224.54 s
Time Step: 4100, Simulation Time: 230.03 s
Time Step: 4200, Simulation Time: 235.26 s
Time Step: 4300, Simulation Time: 241.25 s
Time Step: 4400, Simulation Time: 247.10 s
Time Step: 4500, Simulation Time: 252.91 s
Time Step: 4600, Simulation Time: 258.62 s
Time Step: 4700, Simulation Time: 264.17 s
Time Step: 4800, Simulation Time: 269.85 s
Time Step: 4803, Simulation Time: 270.00 s
STOP: FDS completed successfully <CHID: 914TSF>
```

Figure 1: Command Window of FDS Simulation Time

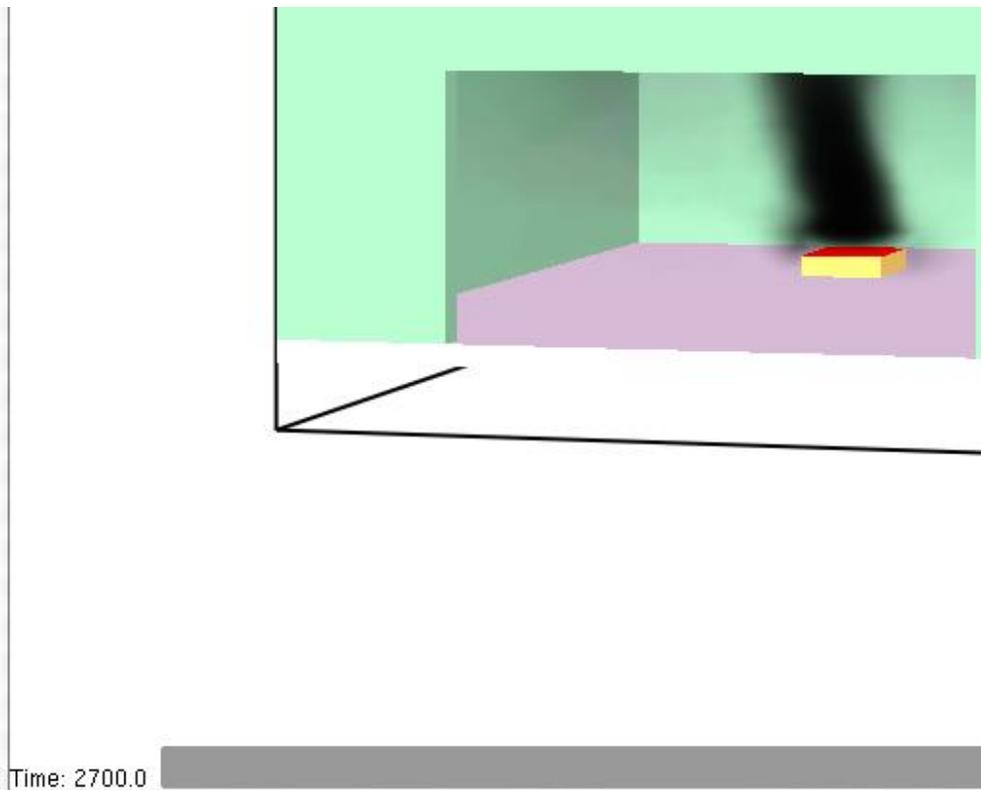


Figure 2: Smokeview Window Simulation Time

SIMULATION MATRIX

In order to evaluate the effect of the TIME_SHRINK_FACTOR on the simulations, the parameters of the simulation (inputs and outputs) are specified. The simulation matrix was developed to be simple enough to test the factors that will have the most effect on the output.

Another factor that is considered for developing the simulation matrix is how practicing design fire protection engineers use FDS. Common uses include the analysis of smoke control systems, exterior building exposure, alternate materials, and/or alternate fuel load and/or arrangement. For example, an authority having jurisdiction currently requires a fire modeling analysis to show that a fire spanning an entire roof or top level of a building will not result in fire spread to the adjacent building. It is required that the simulations be run on the order of thirty minutes to show that the resulting heat flux values (kW/m^2) and surface temperatures do not exceed minimum criteria values that are typically defined by certain standards (such as NFPA 80A). For a majority of the simulation, the fire size is relatively steady along with the heat transfer. Typically the results from twenty minutes in are similar to that of thirty minutes in, but the computational time to get there can be excruciatingly long. This case example will be demonstrated on a smaller scale by evaluating the heat transfer to the walls of the compartment in the test scenarios.

The most important variables determined for this research is the Time_Shrink_Factor itself, and the heat release rate of the fire. The TIME_SHRINK_FACTOR will be included in some of the runs, at either a factor of 2 or 10 and the heat release rate will be steady after ten seconds, or will ramp up over 1800 seconds of the simulation. The fire ramp was determined to be an important factor as the TIME_SHRINK_FACTOR was identified to be intended for use with steady state applications.

The consistent inputs for each scenario includes a simple geometry, (10 meter x 10 meter x 10 meter box), with a natural inlet and outlet vent, as shown in Figure 3. The fire location, fuel properties, and obstruction material properties, mesh size, environmental conditions, are also the same for each scenario.

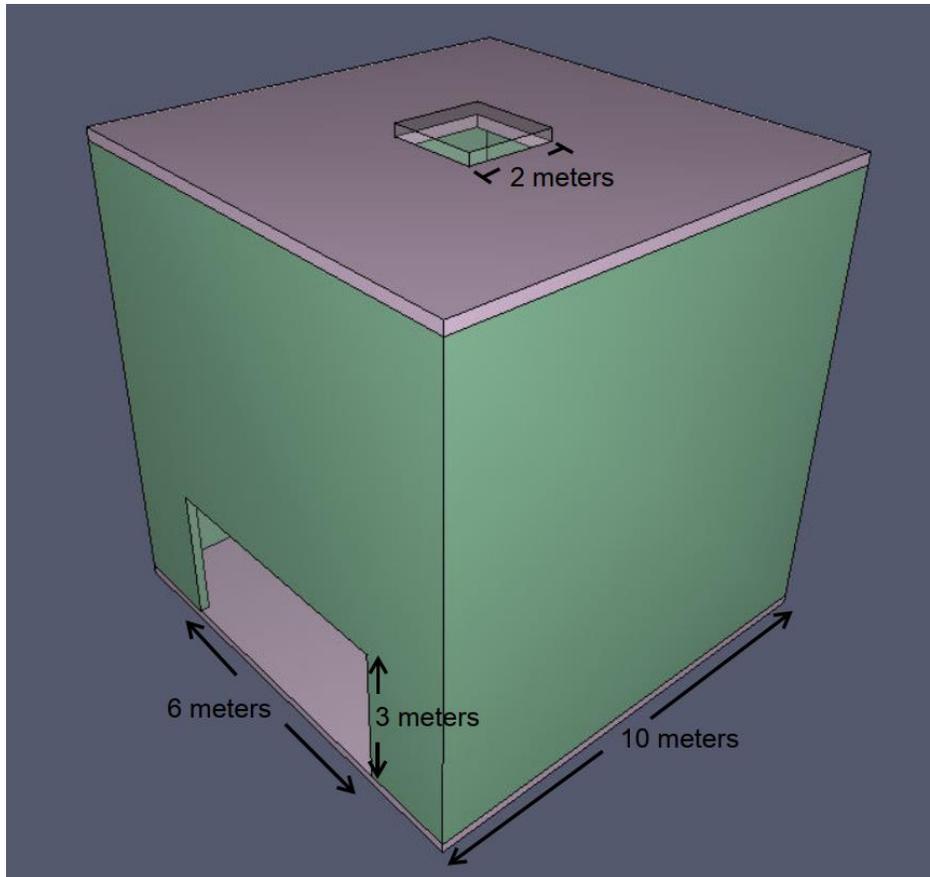


Figure 3: Simulation Geometry

Defined Consistent Inputs

The inputs that will be consistent for each scenario include the following:

Mesh Location: X=0.0,10.0, Y: 0.0,10.0, Z:-1.0,11.0

Mesh Size: 0.25 meters

```
&MESH ID='Mesh01', IJK=40,40,48, XB=0.0,10.0,0.0,10.0,-1.0,11.0/
```

Mesh Boundary as open:

```
&VENT SURF_ID='OPEN', XB=10.0,10.0,0.0,10.0,-1.0,11.0/ Mesh Vent: Mesh01 [XMAX]
&VENT SURF_ID='OPEN', XB=0.0,0.0,0.0,10.0,-1.0,11.0/ Mesh Vent: Mesh01 [XMIN]
&VENT SURF_ID='OPEN', XB=0.0,10.0,10.0,10.0,-1.0,11.0/ Mesh Vent: Mesh01 [YMAX]
&VENT SURF_ID='OPEN', XB=0.0,10.0,0.0,0.0,-1.0,11.0/ Mesh Vent: Mesh01 [YMIN]
&VENT SURF_ID='OPEN', XB=0.0,10.0,0.0,10.0,11.0,11.0/ Mesh Vent: Mesh01 [ZMAX]
&VENT SURF_ID='OPEN', XB=0.0,10.0,0.0,10.0,-1.0,-1.0/ Mesh Vent: Mesh01 [ZMIN]
```

Fuel Properties:

&REAC ID='POLYURETHANE',
FYI='NFPA Babrauskas',
FUEL='REAC_FUEL',
C=6.3,
H=7.1,
O=2.1,
N=1.0,
SOOT_YIELD=0.1

Obstruction Material Properties: Floor and Ceiling - Concrete, and Walls – Gypsum

&MATL ID='CONCRETE',
FYI='NBSIR 88-3752 - ATF NIST Multi-Floor Validation',
SPECIFIC_HEAT=1.04,
CONDUCTIVITY=1.8,
DENSITY=2280.0/
&MATL ID='GYPSUM',
FYI='NBSIR 88-3752 - ATF NIST Multi-Floor Validation',
SPECIFIC_HEAT=1.09,
CONDUCTIVITY=0.17,
DENSITY=930.0/

Location of Room Geometry:

&OBST XB=0.0,10.0,0.0,10.0,-0.25,0.0, SURF_ID='CONCRETE'/ Bottom
&OBST XB=0.0,0.25,0.25,9.75,0.0,10.0, SURF_ID='GYPSUM'/ Sides
&OBST XB=0.0,10.0,0.0,0.25,0.0,10.0, SURF_ID='GYPSUM'/ Sides
&OBST XB=0.0,10.0,9.75,10.0,0.0,10.0, SURF_ID='GYPSUM'/ Sides
&OBST XB=9.75,10.0,0.25,9.75,0.0,10.0, SURF_ID='GYPSUM'/ Sides
&OBST XB=0.0,10.0,0.0,10.0,10.0,10.25, SURF_ID='CONCRETE'/ Top

Fire Location (center of floor):

&OBST XB=4.5,5.5,4.5,5.5,0.25,0.5, SURF_IDS='Fire','INERT','INERT'/ FireLocation

Fire Size (fire area 1 m² x 500 kW/m² = 500 kW):

&SURF ID='Fire',
COLOR='RED',
HRRPUA=500.0,
TAU_Q=-10.0/

Location of Natural Makeup air and Exhaust:

&HOLE XB=-0.025,1.0,2.0,8.0,0.0,3.0/ InVent
&HOLE XB=4.0,6.0,4.0,6.0,9.5,10.5/ OutVent

Defined Consistent Outputs

The outputs will be completely consistent for each scenario, which include the following:

Slice files (Temperature, Velocity, Visibility for Y=5 meters, X=5 meters, and Z=8 meters):

```
&SLCF QUANTITY='TEMPERATURE', PBX=5.0/  
&SLCF QUANTITY='VELOCITY', PBX=5.0/  
&SLCF QUANTITY='VISIBILITY', PBX=5.0/  
&SLCF QUANTITY='TEMPERATURE', PBZ=5.0/  
&SLCF QUANTITY='VELOCITY', PBZ=5.0/  
&SLCF QUANTITY='VISIBILITY', PBZ=5.0/  
&SLCF QUANTITY='TEMPERATURE', PBZ=8.0/  
&SLCF QUANTITY='VELOCITY', PBZ=8.0/  
&SLCF QUANTITY='VISIBILITY', PBZ=8.0/
```

Thermocouples (Gas Temperature of Smoke Layer):

```
&DEVC ID='THCP', QUANTITY='THERMOCOUPLE', XYZ=5.0,5.0,8.0/  
&DEVC ID='THCP01', QUANTITY='THERMOCOUPLE', XYZ=5.0,7.0,8.0/  
&DEVC ID='THCP02', QUANTITY='THERMOCOUPLE', XYZ=5.0,3.0,8.0/
```

Thermocouples (Gas Temperature near lower wall):

```
&DEVC ID='THCP03', QUANTITY='THERMOCOUPLE', XYZ=10.0,5.0,2.0, ORIENTATION=-  
1.0,0.0,0.0/  
&DEVC ID='THCP04', QUANTITY='THERMOCOUPLE', XYZ=10.0,7.0,2.0, ORIENTATION=-  
1.0,0.0,0.0/  
&DEVC ID='THCP05', QUANTITY='THERMOCOUPLE', XYZ=10.0,3.0,2.0, ORIENTATION=-  
1.0,0.0,0.0/
```

Wall Temperature (upper and lower):

```
&DEVC ID='SOLID', QUANTITY='WALL TEMPERATURE', XYZ=9.8,5.0,8.0, IOR=-1/  
&DEVC ID='SOLID01', QUANTITY='WALL TEMPERATURE', XYZ=9.8,7.0,8.0, IOR=-1/  
&DEVC ID='SOLID02', QUANTITY='WALL TEMPERATURE', XYZ=9.8,3.0,8.0, IOR=-1/  
&DEVC ID='SOLID03', QUANTITY='WALL TEMPERATURE', XYZ=0.2,5.0,8.0, IOR=1/  
&DEVC ID='SOLID04', QUANTITY='WALL TEMPERATURE', XYZ=0.2,7.0,8.0, IOR=1/  
&DEVC ID='SOLID05', QUANTITY='WALL TEMPERATURE', XYZ=0.2,3.0,8.0, IOR=1/  
&DEVC ID='SOLID06', QUANTITY='WALL TEMPERATURE', XYZ=9.8,3.0,2.0, IOR=-1/  
&DEVC ID='SOLID07', QUANTITY='WALL TEMPERATURE', XYZ=9.8,5.0,2.0, IOR=-1/  
&DEVC ID='SOLID08', QUANTITY='WALL TEMPERATURE', XYZ=9.8,7.0,2.0, IOR=-1/
```

Smoke Layer Height:

```
&DEVC ID='LAYER', QUANTITY='LAYER HEIGHT', XB=5.0,5.0,2.0,2.0,0.0,10.0/  
&DEVC ID='LAYER01', QUANTITY='LAYER HEIGHT', XB=5.0,5.0,8.0,8.0,0.0,10.0/
```

Mass Flow Above Fire:

```
&DEVC ID='FLOW01', QUANTITY='MASS FLOW', XB=4.0,6.0,4.0,6.0,1.0,1.0/
```

Volume Flow Above Fire:

```
&DEVC ID='FLOW', QUANTITY='VOLUME FLOW', XB=4.0,6.0,4.0,6.0,1.0,1.0/
```

Beam Detector Device:

```
&DEVC ID='BEAM', QUANTITY='PATH OBSCURATION', XB=2.0,8.0,5.0,5.0,8.0,8.0/
```

Boundary Quantity:

```
&BNDF QUANTITY='ADIABATIC SURFACE TEMPERATURE'/  
&BNDF QUANTITY='BACK WALL TEMPERATURE'/  
&BNDF QUANTITY='NET HEAT FLUX'/  
&BNDF QUANTITY='HEAT TRANSFER COEFFICIENT'/  
&BNDF QUANTITY='INCIDENT HEAT FLUX'/  
&BNDF QUANTITY='WALL TEMPERATURE'/
```

Defined Variable Inputs

Fire Ramp:

10 Second Ramp:

```
&SURF ID='Fire',  
  COLOR='RED',  
  HRRPUA=500.0,  
  TAU_Q=-10.0/
```

1800 Second Ramp:

```
&SURF ID='Fire',  
  COLOR='RED',  
  HRRPUA=500.0,  
  TAU_Q=-1800.0/
```

Time Shrink Factor:

```
&TIME TIME_SHRINK_FACTOR=2. /
```

```
&TIME TIME_SHRINK_FACTOR=10. /
```

Table 1 shows the simulation matrix of the six possible scenarios, noting the heat release rate and time shrink factor specified for that scenario.

Table 1: Simulation Matrix

Scenario	Heat Release Rate		Time Shrink Factor			
	Steady	Growth	None	2	5	10
1	X		X			
2	X			X		
3	X				X	
4	X					X
5		X	X			
6		X		X		
7		X			X	
8		X				X

RESULTS

Run Time

Table 2 shows the reduced run time as a result of using the TIME_SHRINK_FACTOR. The reduced run time corresponds with the TIME_SHRINK_FACTOR used. For example, the simulations that used the TIME_SHRINK_FACTOR of 10 ran approximately 10 times faster.

Table 2: Simulation Run Time Results

Scenario	Simulation Time	
	TSF	Run Time Reduced
1	NA	NA
2	2	1.9
3	5	4.7
4	10	9.2
5	NA	NA
6	2	2.1
7	5	5
8	10	10

Lower Wall Temperatures

Wall temperature devices measured the temperature at a lower portion of the wall, which is near the fire and below the smoke layer. Figure 4 and 5 (steady and growth) show the temperature measured for the various scenarios and it can be seen that the results are consistent between the simulations. This shows that the TIME_SHRINK_FACTOR does not have an effect on these results.

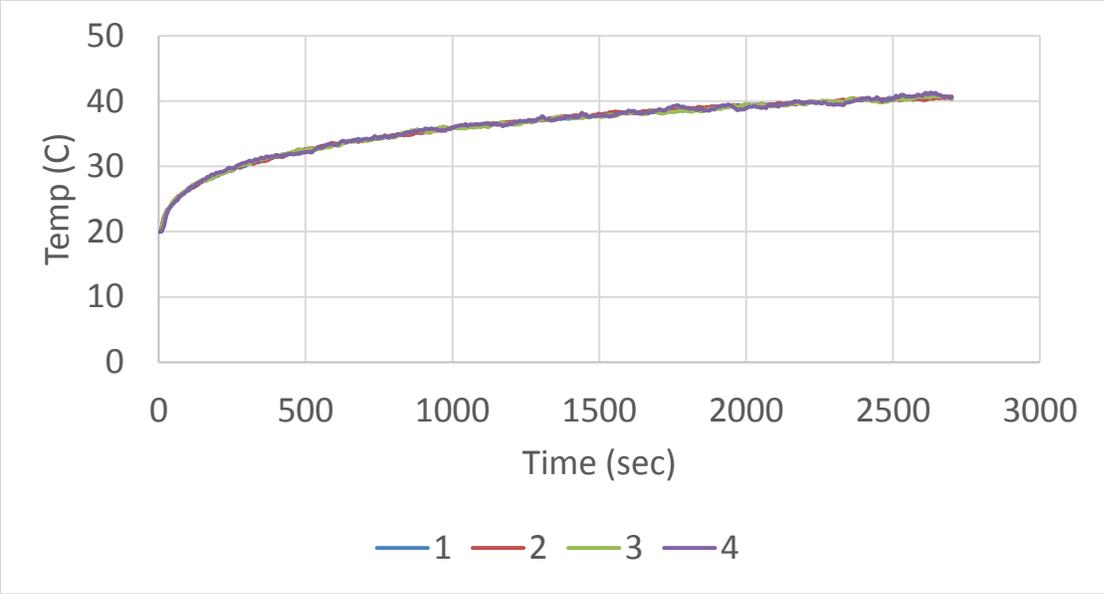


Figure 4: Lower Wall Temperatures for Scenario 1 through 4 (Steady)

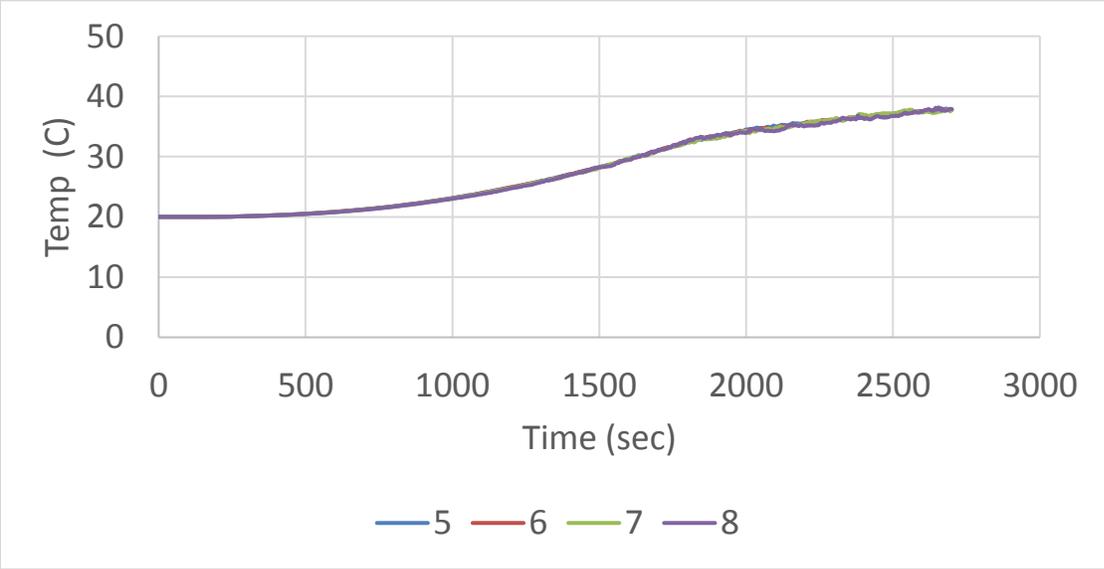


Figure 5: Lower Wall Temperatures for Scenario 5 through 8 (Growth)

Calculated Heat Release Rate

Figures 6 and 7 (steady and growth) show the resulting calculated heat release rate for each of the scenarios. It can be seen that for the scenarios with the TIME_SHRINK_FACTOR, the heat release rate is much less steady than the regular simulation. The heat release rate of the highest TIME_SHRINK_FACTOR varies between 550 and 450 kW, whereas the regular simulation varies between 510 and 490 kW.

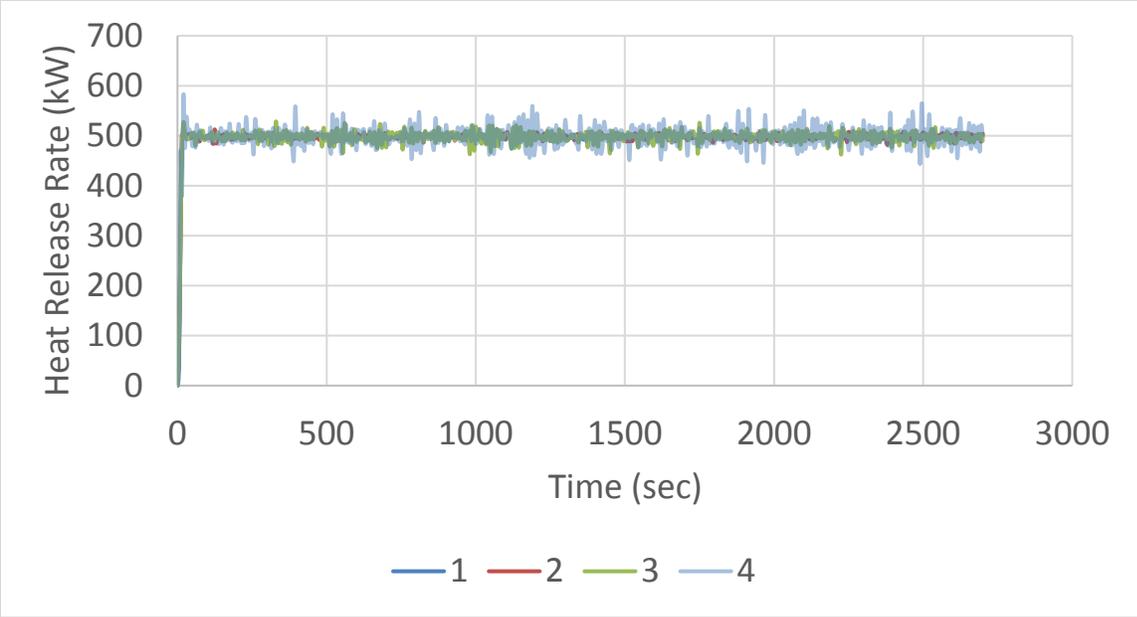


Figure 6: Heat Release Rate for Scenario 1 through 4 (Steady)

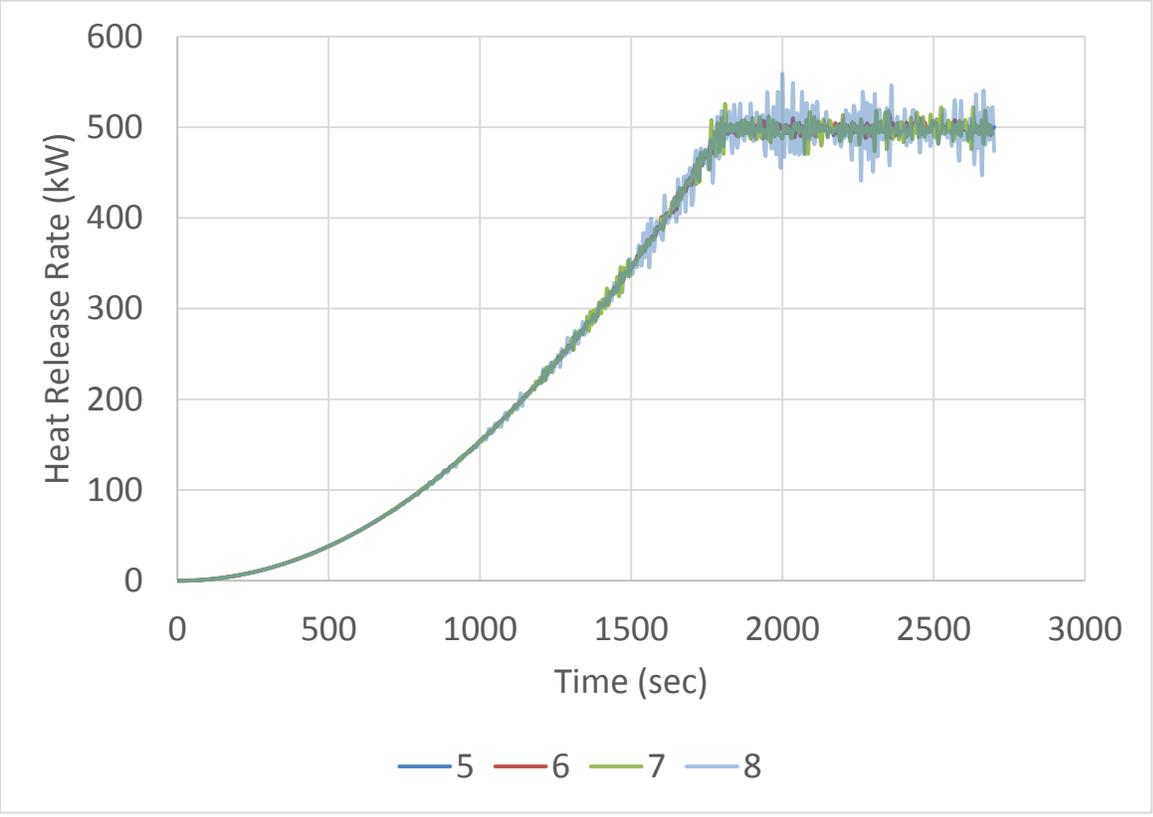


Figure 7: Heat Release Rate for Scenario 5 through 8 (Growth)

Smoke Layer Temperature and Location

Figures 8 and 9 show the smoke layer temperatures for each of the scenarios. It can be seen that for the scenarios with the TIME_SHRINK_FACTOR, the smoke layer temperatures are lower than the regular simulation.

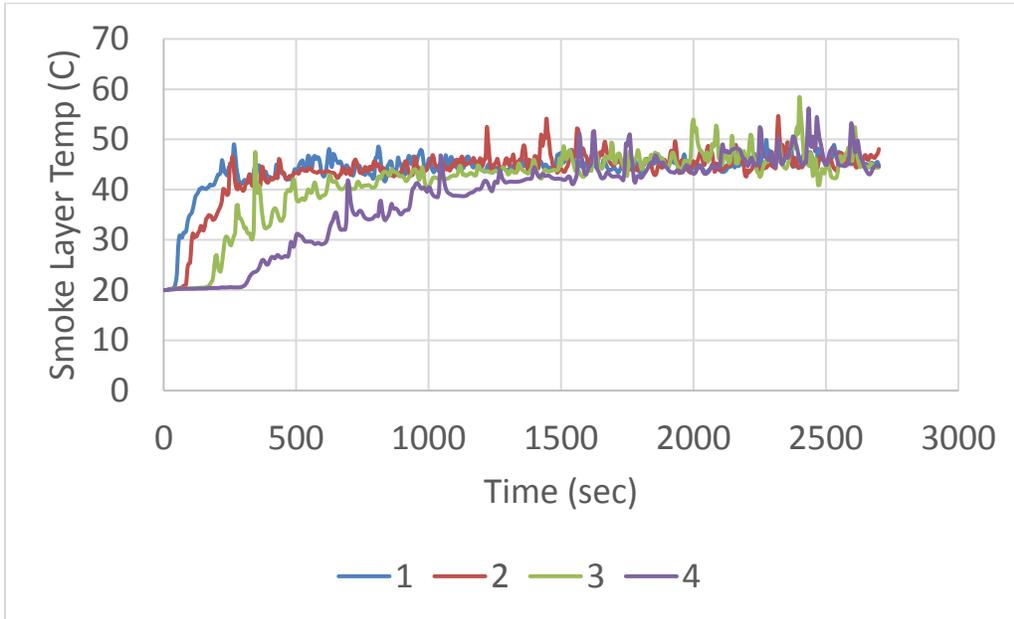


Figure 8: Smoke Layer Temperature for Scenario 1 through 4 (Steady)

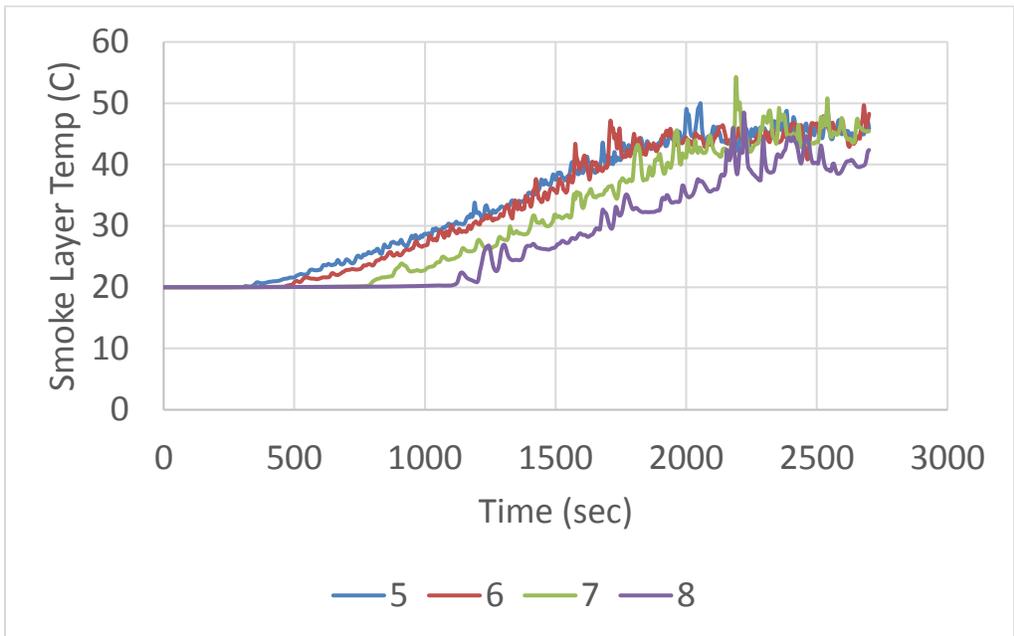


Figure 9: Smoke Layer Temperature for Scenario 5 through 8 (Growth)

Figures 10 and 11 show the smoke layer interface height for each of the scenarios. It can be seen that there is a delay in the smoke layer interface descending for the TIME_SHRINK_FACTOR simulations.

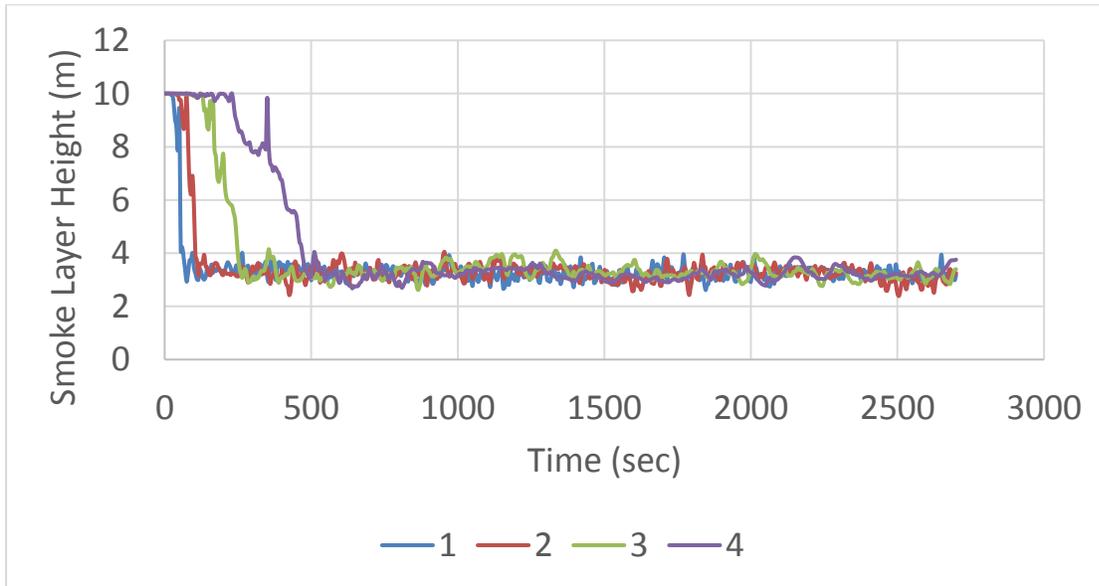


Figure 10: Smoke Layer Height for Scenario 1 through 4 (Steady)

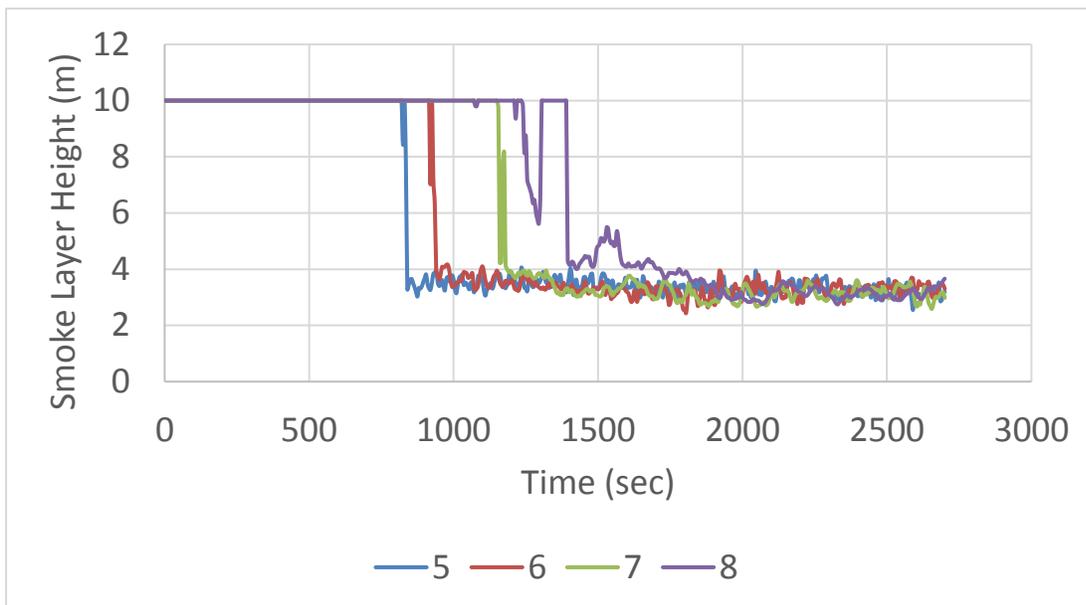


Figure 11: Smoke Layer Height for Scenario 5 through 8 (Growth)

Upper Wall Temperatures

Similarly to the smoke layer temperature being lower for the TIME_SHRINK_FACTOR simulations, the upper layer wall temperature is lower as well, as shown in Figures 12 and 13.

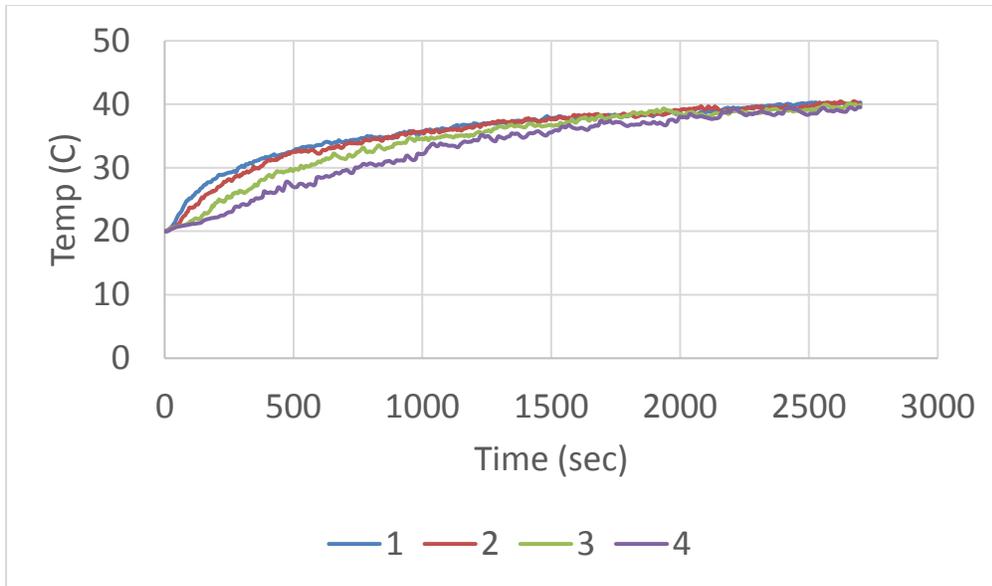


Figure 12: Upper Wall Temperature for Scenario 1 through 4 (Steady)

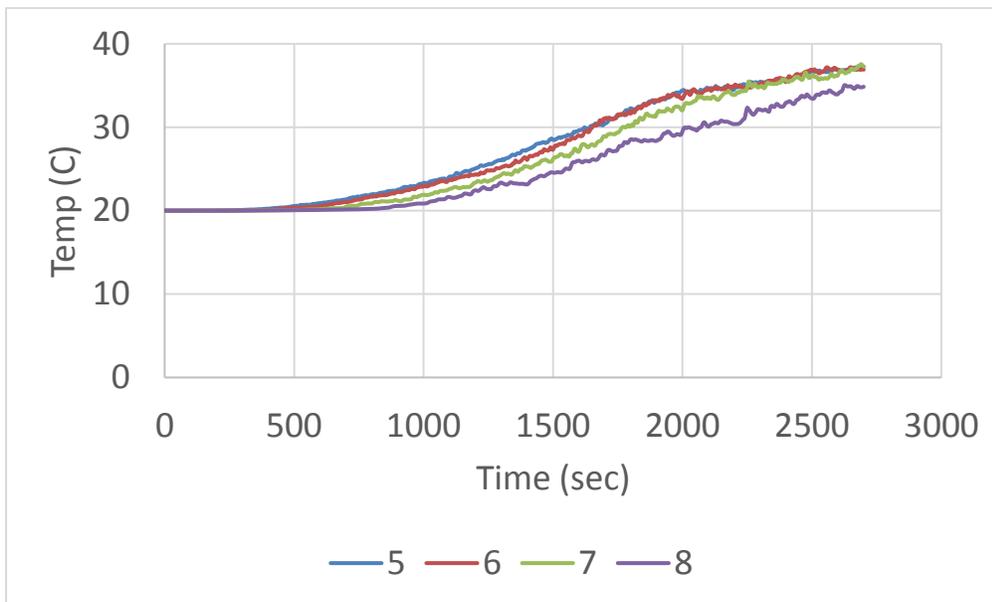


Figure 13: Upper Wall Temperature for Scenario 5 through 8 (Growth)

CONCLUSION

The TIME_SHRINK_FACTOR allows for heat transfer to occur more rapidly by reducing the specific heats of the materials within the simulation. The results with and without the TIME_SHRINK_FACTOR have produced similar results for the heat transfer to areas close to the fire. Other results within the simulation such as smoke production and temperature within the room have been shown to be affected by the TIME_SHRINK_FACTOR. The simulations that utilized the TIME_SHRINK_FACTOR resulted in lower upper layer temperatures and less dense smoke, the larger the TIME_SHRINK_FACTOR and the less the fire is steady, the more it affected the results. This factor could be considered to be used when the smoke production is not of interest and does not affect the areas of interest. The example noted previously of a building fire exposure study could be considered for use of this factor as the only area of interest (wall heat transfer) is affected by the fire only, and

not from the smoke interacting with the wall because the smoke within the simulation is free to move upward into the open air. This case should be tested however, and just as any other method of using this factor for practicing fire protection engineering.

REFERENCES

McGrattan, K., Hostikka, S., McDermott, R., Jason, F., Vanella, M. (2018), "Fire Dynamics Simulator User's Guide," *NIST Special Publication 1019 Sixth Edition*, p. 34.