Anwendungsbaustein - Auswertung von fds-Daten

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Preamble

Citation suggestion

Lukas Arnold, Simone Arnold, Florian Bagemihl, Matthias Baitsch, Marc Fehr, Maik Poetzsch, and Sebastian Seipel. 2024. "Building blocks of Computer-Aided Data Analysis - Application Module for fds Data" https://github.com/bausteine-der-datenanalyse/a-auswertung_fds_daten.

BibTeX-Vorlage

```
@misc{BCD-Styleguide-2024,
 title={Bausteine Computergestützter Datenanalyse. Application module for fds data},
 author={Arnold, Lukas and Arnold, Simone and Baitsch, Matthias and Fehr, Marc and Poetzsch,
 year={2024},
 url={https://github.com/bausteine-der-datenanalyse/a-auswertung_fds_daten}}
```

Intro

Requirements

- Basic knowledge of python
- Importing packages
- NumPy basics
- Pandas basics
- Plotting with matplotlib
- Basic knowledge in simulating fires

Used packages and data sets

- NumPy
- pandas
- matplotlib
- fdsreader

Time required

Geschätzte Bearbeitungszeit: 4h

Learning objectives

- Reading in data using the fdsreader
- Analyzing the data to perform an ASET analysis

1 Introduction ASET

ASET (Available Safe Egress Time) is a critical concept in fire safety engineering that represents the time available for occupants to safely evacuate a building before conditions become untenable due to fire, smoke, or heat. It is calculated based on factors such as fire growth rate, detection time, and the building's design features, including exits and fire suppression systems. Ensuring that the ASET exceeds the Required Safe Egress Time (RSET) is essential for developing effective evacuation plans and enhancing the safety of building occupants during an emergency.

1.1 Data acquisation

The data we will look at were generated using the Fire Dynamics Simulator (FDS). FDS (Fire Dynamics Simulator) is a computational fluid dynamics model used to simulate fire-driven fluid flow, allowing for the analysis and prediction of fire behavior and its impact on buildings and environments.

> ⚠ Warning
>
> This building block wont go any further into simulations and fds. The resulting simulation data used in this block will be provided as a download.

2 Fdsreader

In order to analyse simulation data computed by FDS with Python, the group of Prof. Lukas Arnold has developed the Python module fdsreader. Its aim is to read most data output formats generated by FDS and map them to Python data structures.

The freely available and open source. The source code is hosted at GitHub: FireDynamics/fdsreader and there is also an API documentation.

2.1 Installing and importing the package

The fdsreader module can be installed via pip (see also the GitHub repository):

```
pip install fdsreader
```

To learn the basic usage of the fdsreader module we will look at a simple FDS scenario. Lets first import the module:

```
import fdsreader
```

Since we will also plot the data we will import `matplotlib`too.

```
import matplotlib.pyplot as plt
```

2.2 Choosing the correct folder

Next, the reader needs to be pointed to the directory, which contains the simulation data, especailly the smokeview file.

```
# define the path to the data
path_to_data = '../skript/01-data/first_example'

sim = fdsreader.Simulation(path_to_data)
```

The `Simulation` object `sim` contains now all the information and data about the simulaiton output:

```
sim
```

```
Simulation(chid=StecklerExample,
           meshes=1,
           obstructions=7,
           slices=5,
           data_3d=5,
           smoke_3d=3,
           devices=4)
```

The variable `sim` contains information about the mesh (`MESH`), four slices (`SLCF`) and four point measurements (`DEVC`). The additional device – there were just three defined in the FDS input file – is the time column.

2.3 Device Data

Devices in FDS

Devices act like virtual sensors, allowing one to record data such as temperature, heat flux, gas concentration, velocity, and more, at specific locations within the simulation domain. This data can be crucial for understanding the behavior of fire and smoke under different conditions.
A device can get a label (`ID`), which makes it much easier to identify in the comma separated value (CSV) file created during the simulation. It needs a location and a quantity.
Locations can be provided in different ways, we focus her on a single point using `XYZ`. However, lines, planes and volumes are possible as well.
The `QUANTITY` parameter expects a string to define what values are to be recorded. As an example, let's take the gas temperature, using `TEMPERATURE`.

The simplest data set is the output of the DEVC directives. The available data and meta information can be directly printed:

```
# short reference for convinience, i.e. `devc` contains all devices
devc = sim.devices
print(devc)
```

```
[Device(id='Time', xyz=(0.0, 0.0, 0.0), quantity=Quantity('TIME')),
Device(id='Temp_Door_Low', xyz=(1.45, 0.05, 0.1), quantity=Quantity('TEMPERATURE')),
Device(id='Temp_Door_Mid', xyz=(1.45, 0.05, 1.0), quantity=Quantity('TEMPERATURE')),
Device(id='Temp_Door_High', xyz=(1.45, 0.05, 1.65), quantity=Quantity('TEMPERATURE'))]
```

The Device class contains all relevant information, see device documentation.

```python
for i in devc:
    print(f"ID: {i.id},\t quantity: {i.quantity_name}, \t position: {i.position}")
```

```
ID: Time,    quantity: TIME,      position: (0.0, 0.0, 0.0)
ID: Temp_Door_Low,   quantity: TEMPERATURE,       position: (1.45, 0.05, 0.1)
ID: Temp_Door_Mid,   quantity: TEMPERATURE,       position: (1.45, 0.05, 1.0)
ID: Temp_Door_High,  quantity: TEMPERATURE,       position: (1.45, 0.05, 1.65)
```

Individual devices, including the time column, are accessable as dictironary entries using their ID as key. The data of each individual device (Device.data) is stored as a numpy array:

```python
type(devc['Temp_Door_Mid'].data)
```

```
numpy.ndarray
```

The length matches the expected value, i.e. 1801, as the simulation time was and the divices were writen out every second, including the initial time step, here at `t = 0s`.

```python
len(devc['Time'].data)
```

```
1801
```

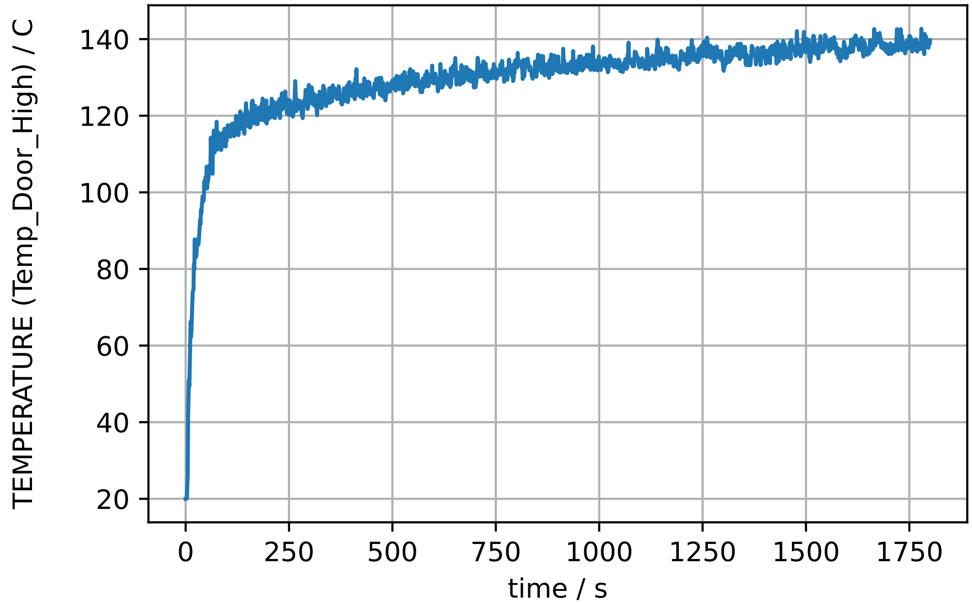
A raw look at the data (`Device.data`):

```python
devc['Temp_Door_Mid'].data
```

```
array([ 20.       ,  20.002083,  20.034418, ..., 105.32822 , 114.82179 ,
       115.01705 ], dtype=float32)
```

The device data can be also visualised with matplotlib:

```python
# create the plot
plt.plot(devc['Time'].data, devc['Temp_Door_High'].data)

# label the axes
plt.xlabel("time / s")
devc_id = devc['Temp_Door_High'].id
devc_q = devc['Temp_Door_High'].quantity_name
devc_u = devc['Temp_Door_High'].unit
plt.ylabel(f"{devc_q} ({devc_id}) / {devc_u}")

# add a grid
plt.grid()
```

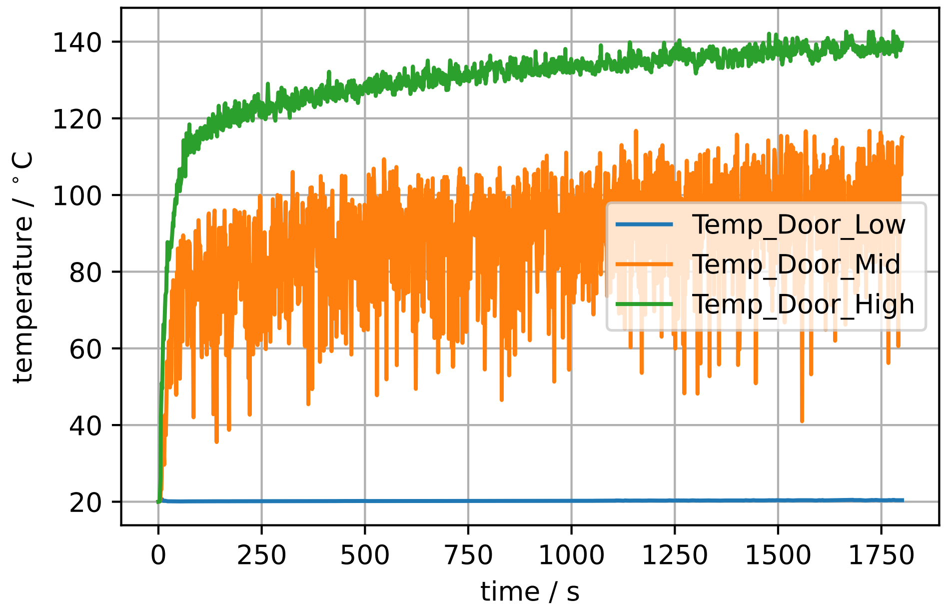


In the same manner a set of devices can be plotted at once. Like all devices with names starting with Temp_:

```python
# loop over all devices
for i in devc:

    # consider only devices with an ID that starts with 'Temp_'
    if not i.id.startswith('Temp_'):
        continue

    plt.plot(devc["Time"].data, i.data, label=i.id)
```

```
plt.legend()
plt.xlabel("time / s")
plt.ylabel('temperature / $^\circ$C')
plt.grid()
```

```
<>:12: SyntaxWarning: invalid escape sequence '\c'
<>:12: SyntaxWarning: invalid escape sequence '\c'
/var/folders/p_/ks3trxjx0jd839_g4g0vm4nc0000gn/T/ipykernel_85247/1295739546.py:12: SyntaxWarn
  plt.ylabel('temperature / $^\circ$C')
```

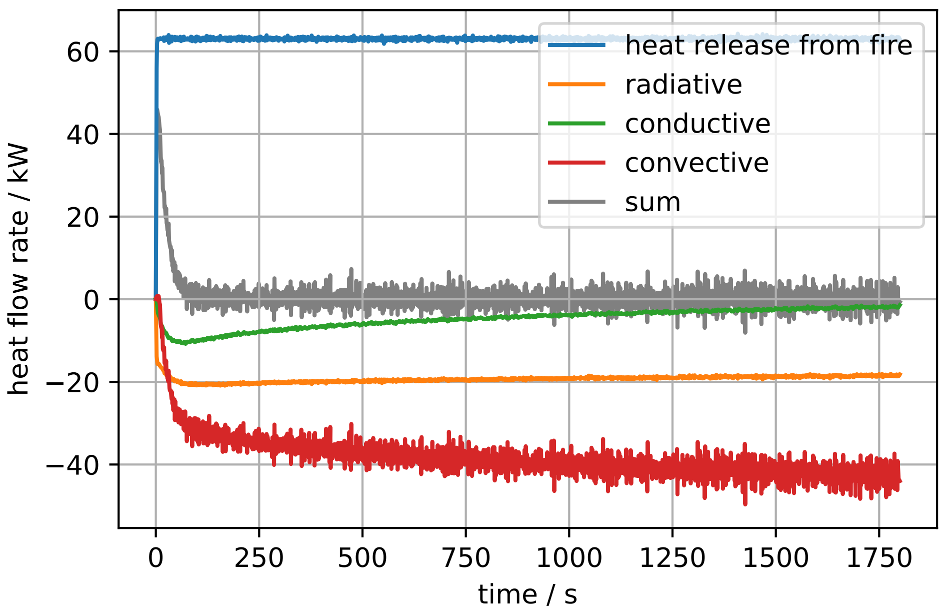


2.4 HRR Data

> Heat Release Rate (HRR)
>
> The crucial parameter in fire modeling, representing the rate at which energy is released by a fire, typically measured in kilowatts (kW) or megawatts (MW).

In the same fashion as the `DEVC` data, the data written to the `HRR` file can be directly accessed. It is not stored in the `devices` but in the `hrr` element of the `Simulation` object.

```python
plt.plot(sim.hrr['Time'], sim.hrr['HRR'], label='heat release from fire')

plt.plot(sim.hrr['Time'], sim.hrr['Q_RADI'], label='radiative')
plt.plot(sim.hrr['Time'], sim.hrr['Q_COND'], label='conductive')
plt.plot(sim.hrr['Time'], sim.hrr['Q_CONV'], label='convective')

plt.plot(sim.hrr['Time'],
         sim.hrr['HRR'] + sim.hrr['Q_RADI'] + sim.hrr['Q_COND'] + sim.hrr['Q_CONV'],
         color='grey', label='sum', zorder=0)

plt.xlabel('time / s')
plt.ylabel('heat flow rate / kW')
plt.legend()
plt.grid()
```



2.5 Slice Data

> Slice data
>
> Sclices are a type of output that allows you to visualize the distribution of specific quantities (e.g., temperature, velocity, smoke concentration) within a plane of the simulation domain. These slices are essentially cross-sectional views of the data, providing insight into how these quantities vary within a specific area of the simulated environment.

Data generated by `SLCF` directives span over two or three spatial dimensions plus the time dimension. Besides that, they can be distributed across multiple meshes.

The data of a slice is stored for each mesh individually. In this simple example, there is only a single mesh, yet for formal consistency it still needs to be referred.

The data structure is as follows:

```
sim.slices[sliceid][meshid].data[timestep, direction1, direction2]
```

where `sliceid` is just the index of the slice, `meshid` is the index of the mesh, here in this example 0, and the reference to the data is given by the time step id and then the two spatial indices (for two dimensional slices).

In general there are multiple slice objects available:

```python
# print available slice data
for slice in sim.slices:
    print(f"Slice Type [2D/3D]: {slice.type}\n  Quantity: {slice.quantity.name}\n",
          f" Physical Extent: {slice.extent}\n  Orientation [1/2/3]: {slice.orientation}\n")
```

```
Slice Type [2D/3D]: 2D
  Quantity: TEMPERATURE
  Physical Extent: Extent([0.00, 0.00] x [-1.40, 1.40] x [0.00, 2.20])
  Orientation [1/2/3]: 1

Slice Type [2D/3D]: 2D
  Quantity: TEMPERATURE
  Physical Extent: Extent([-1.40, 2.60] x [0.00, 0.00] x [0.00, 2.20])
  Orientation [1/2/3]: 2

Slice Type [2D/3D]: 2D
  Quantity: W-VELOCITY
  Physical Extent: Extent([0.00, 0.00] x [-1.40, 1.40] x [0.00, 2.20])
```

```
  Orientation [1/2/3]: 1

Slice Type [2D/3D]: 2D
  Quantity: U-VELOCITY
  Physical Extent: Extent([-1.40, 2.60] x [0.00, 0.00] x [0.00, 2.20])
  Orientation [1/2/3]: 2

Slice Type [2D/3D]: 2D
  Quantity: W-VELOCITY
  Physical Extent: Extent([-1.40, 2.60] x [-1.40, 1.40] x [1.80, 1.80])
  Orientation [1/2/3]: 3
```

There are multiple ways to find the right slice in the set of all slices. One way is to filter for a quantity using the `filter_by_quantity` function or choose a slice by its ID.

```
# get the W-VELOCITY slice(s)
w_slice = sim.slices.filter_by_quantity("W-VELOCITY")
print(w_slice)
```

```
SliceCollection([Slice([2D] quantity=Quantity('W-VELOCITY'), cell_centered=False, extent=Exte
Slice([2D] quantity=Quantity('W-VELOCITY'), cell_centered=False, extent=Extent([-1.40, 2.60]
```

Another way is to select a slice based on its distance to a given point.

```
# select slice, by its distance to a given point
slc = w_slice.get_nearest(x=1, z=2)
print(slc)
```

```
Slice([2D] quantity=Quantity('W-VELOCITY'), cell_centered=False, extent=Extent([-1.40, 2.60]
```

To access the actual slice data, the actual mesh and a point in time needs to be specified. In this example, there is only one mesh, thus the index is 0. The function `get_nearest_timestemp` helps to find the right time index.

```
# choose and output the time step, next to t=75 s
it = slc.get_nearest_timestep(25)
print(f"Time step: {it}")
print(f"Simulation time: {slc.times[it]}")
```

```
Time step: 25
Simulation time: 25.02111
```

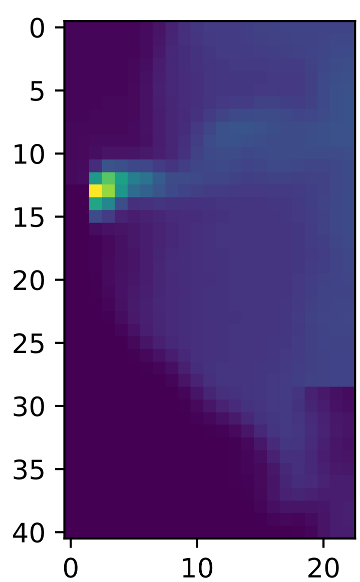
The following example illustrates the visualisation of the data and steps needed to adjust the representation. The needed adjustments are due to the data orientation expected by the `imshow` function.

```
# choose the temperature slice in y-direction
slc = sim.slices.filter_by_quantity('TEMPERATURE').get_nearest(x=3, y=0)
print(slc)
# only one mesh
slc_data = slc[0].data
print(slc_data)
```

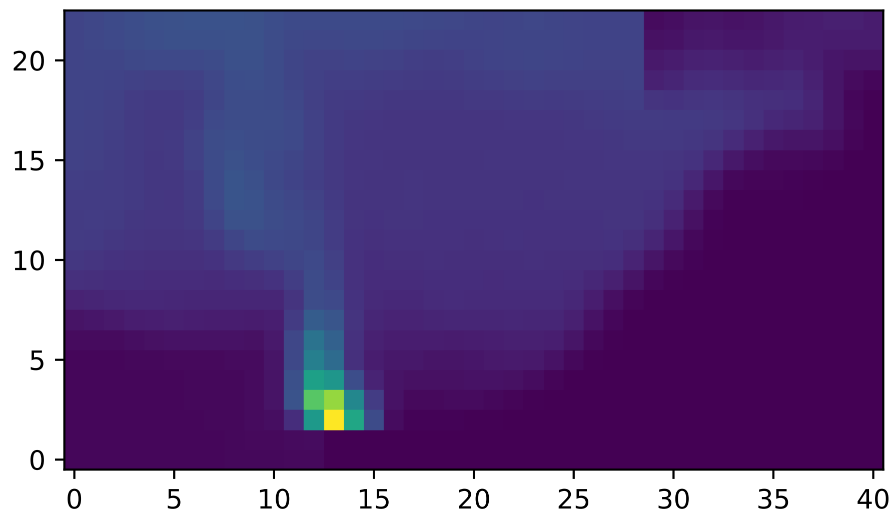
```
Slice([2D] quantity=Quantity('TEMPERATURE'), cell_centered=False, extent=Extent([-1.40, 2.60]
[[[ 20.         20.         20.        ...  20.         20.         20.       ]
  [ 20.         20.         20.        ...  20.         20.         20.       ]
  [ 20.         20.         20.        ...  20.         20.         20.       ]
  ...
  [ 20.         20.         20.        ...  20.         20.         20.       ]
  [ 20.         20.         20.        ...  20.         20.         20.       ]
  [ 20.         20.         20.        ...  20.         20.         20.       ]]

 [[ 20.030926  20.031328  20.032204 ...  20.001385  20.001268  20.00117 ]
  [ 20.030703  20.031597  20.033634 ...  20.001493  20.001345  20.001238]
  [ 20.031723  20.033785  20.038801 ...  20.001757  20.001535  20.001389]
  ...
  [ 20.006077  20.004908  20.002953 ...  20.001383  20.001154  20.00104 ]
  [ 20.005085  20.004053  20.00236  ...  20.00129   20.001116  20.001026]
  [ 20.004608  20.003656  20.0021   ...  20.00125   20.001104  20.001026]]

 [[ 20.12404   20.126698  20.133305 ...  20.026028  20.02525   20.025595]
  [ 20.116137  20.11882   20.12633  ...  20.02626   20.025606  20.02608 ]
  [ 20.114033  20.117645  20.128752 ...  20.02802   20.027351  20.027908]
  ...
  [ 20.018784  20.016739  20.013128 ...  20.00563   20.004776  20.004353]
  [ 20.015898  20.014067  20.010876 ...  20.005054  20.004427  20.004118]
  [ 20.01441   20.012737  20.00983  ...  20.004791  20.004278  20.00403 ]]

 ...

 [[ 44.00391   43.917053  43.920734 ... 143.89009  142.69537  142.16621 ]
  [ 44.004223  43.863914  43.708996 ... 143.29715  142.09953  141.6622  ]
  [ 43.81018   43.64982   43.4085   ... 142.64955  141.90448  141.75969 ]
  ...
```

```
 [ 20.284891  20.19156   20.076902 ...  90.631195  78.81051   72.00585 ]
 [ 20.218634  20.140545  20.047134 ...  56.04536   43.176456  39.645744]
 [ 20.151264  20.09307   20.028439 ...  34.67456   27.534237  27.970665]]

[[ 45.228874  45.115242  44.938766 ... 150.18481  150.12732  149.83371 ]
 [ 44.492287  44.350613  44.180614 ... 149.79759  150.0778   149.77635 ]
 [ 43.646873  43.590538  43.562504 ... 147.7298   148.82109  149.29768 ]
 ...
 [ 20.281096  20.186028  20.071451 ... 106.69953   93.09295   83.79199 ]
 [ 20.205025  20.13359   20.046276 ...  80.62758   71.11945   62.30358 ]
 [ 20.16152   20.102564  20.033293 ...  65.56552   56.724525  46.839134]]

[[ 42.762764  42.892406  42.67096  ... 146.0912   145.20709  144.58104 ]
 [ 43.14627   43.263447  43.141045 ... 145.02187  144.6713   143.69063 ]
 [ 43.753468  43.769325  43.798447 ... 141.0417   142.32797  141.77148 ]
 ...
 [ 20.268656  20.194078  20.08938  ...  72.89162   70.64532   65.348694]
 [ 20.206676  20.136755  20.052374 ...  59.554634  49.809177  42.573883]
 [ 20.180956  20.111738  20.035168 ...  48.16472   36.145966  31.134487]]]
```

```
# Initial visualasation of the data at time t=50 s
it = slc.get_nearest_timestep(50)
plt.imshow(slc_data[it])
```

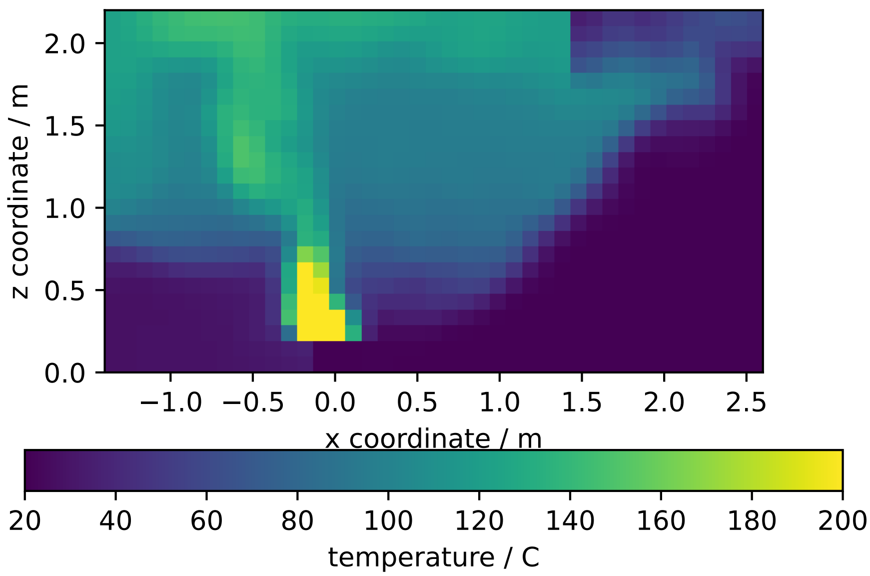


```
# Access the transpose data using ndarray.T and set the origin of the output
plt.imshow(slc_data[it].T, origin='lower')
```

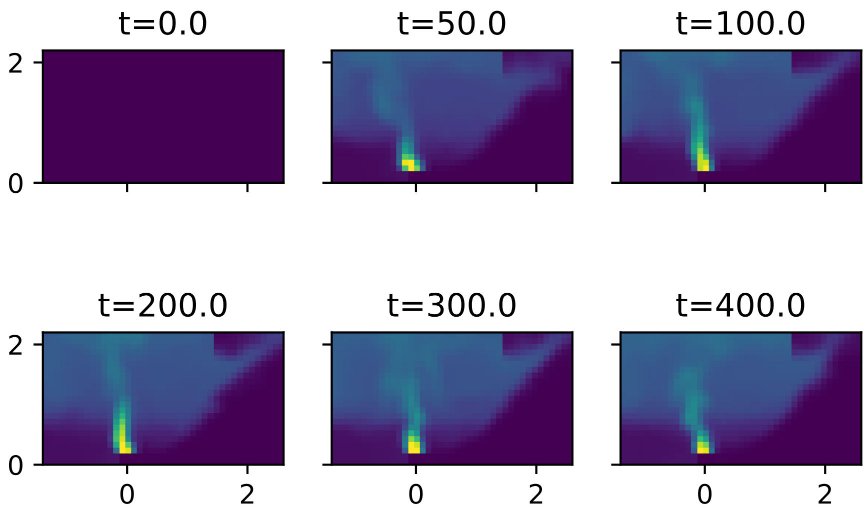



```
# Initial visualasation of the data at time t=50 s
# Finally, also the extend is specified to move from index to physical space
# Additionally, the maximal value is set using the vmax argument
plt.imshow(slc_data[it].T,
           origin='lower',
           vmax=200,
           extent=slc.extent.as_list())
plt.colorbar(label='temperature / C', orientation='horizontal')
plt.xlabel('x coordinate / m')
plt.ylabel('z coordinate / m')
```

```
Text(0, 0.5, 'z coordinate / m')
```




```
# Example for a multi plot
list_t = [0, 50, 100, 200, 300, 400]
fig, axs = plt.subplots(2,3, sharex=True, sharey=True)
for i in range(len(list_t)):
    it = slc.get_nearest_timestep(list_t[i])
    axs.flat[i].imshow(slc_data[it].T,
                       vmin=20,
                       vmax=400,
                       origin='lower',
                       extent=slc.extent.as_list())
    axs.flat[i].set_title(f"t={slc.times[it]:.1f}")
```



t=0.0
t=50.0
t=100.0
t=200.0
t=300.0
t=400.0
2
0
2
0
0
2
0
2
0
2

3 Available safe egress time

```python
import fdsreader
import matplotlib.pyplot as plt
import numpy as np
```

This example demonstrates an analysis of slice data, here to determine the map of available safe egress time (ASET) and the temporal evolution of the smoke layer height. The used scenario is a multi-room appartment.

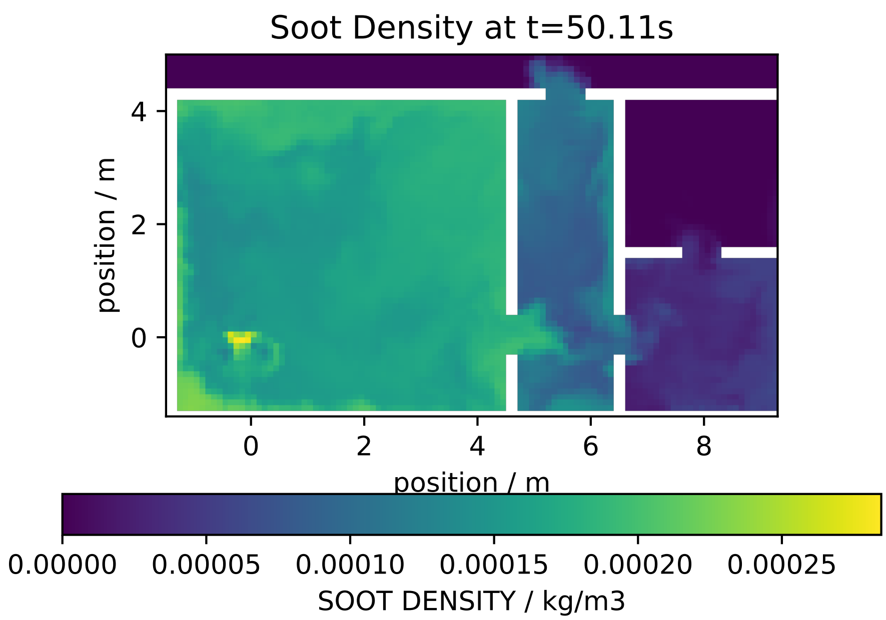
```python
path_to_data = '../skript/01-data/apartment_01'

sim = fdsreader.Simulation(path_to_data)
print(sim)
```

```
Simulation(chid=Appartment,
           meshes=8,
           obstructions=23,
           slices=20,
           data_3d=5,
           smoke_3d=3)
```

```python
# get the soot density slice, normal to z at 1.5m height
slc = sim.slices.get_by_id('SootDensityZ_1.5m')

# as the simulation is based on multiple meshes, a global
# data structure is created, walls are represented as
# non-valid data points, i.e. nan
slc_data = slc.to_global(masked=True, fill=np.nan)
```

First, a visualisation of the data at a selected point is done with the `imshow` function.

```
# find the time index
it = slc.get_nearest_timestep(50)

# visualise the data
plt.imshow(slc_data[it,:,:].T, origin='lower', extent=slc.extent.as_list())

# add labels
plt.title(f'Soot Density at t={slc.times[it]:.2f}s')
plt.xlabel('position / m')
plt.ylabel('position / m')
plt.colorbar(orientation='horizontal', label=f'{slc.quantity.name} / {slc.quantity.unit}' )
```



Now, the local ASET values are computed:

1. Iterate over all spatial elements of the slice
2. Determine all points in time which exceed the tenability threshold
3. f this happens at any time, set the first time to be the local ASET value

```
# set arbitrary values as tenability threshold
soot_density_limit = 1e-4

# create a map with max ASET as default value
aset_map = np.full_like(slc_data[0], slc.times[-1])
```

```python
# set walls to nan
aset_map[np.isnan(slc_data[0,:,:])] = np.nan

# 1D loop over all array indices, ix is a two dimensional index
for ix in np.ndindex(aset_map.shape):

    # find spatialy local values which exceed the given limit
    local_aset = np.where(slc_data[:, ix[0], ix[1]] > soot_density_limit)[0]

    # if any value exists
    if len(local_aset) > 0:
        # use the first, i.e. first in time, as the local ASET value
        aset_map[ix] = slc.times[local_aset[0]]
```

With the computed map, a graphical respresentation of the ASET map is done the same way as with the other quantities. Here, a discrete color map is used.

```python
# create a discrete (12 values) color map
# cmap = matplotlib.cm.get_cmap('jet_r', 12)
cmap = plt.cm.get_cmap('jet_r', 12)

# visualise the data
plt.imshow(aset_map.T, origin='lower', extent=slc.extent.as_list(), cmap=cmap)
plt.title(f'ASET Map with Soot Density Limit of {soot_density_limit:.1e}')
plt.xlabel('x position / m')
plt.ylabel('y position / m')
plt.colorbar(orientation='horizontal', label='time / s' );

# save output to file
#plt.savefig('figs/appartment_aset_map.svg', bbox_inches='tight')

plt.close()
```

```
/var/folders/p_/ks3trxjx0jd839_g4g0vm4nc0000gn/T/ipykernel_84755/4244811350.py:3: Matplotlib
  cmap = plt.cm.get_cmap('jet_r', 12)
```

3.1 Smoke layer

In this example, the smoke layer height is analysed. The distinction made here is based on a simple threshold in temperature: The local smoke layer height is given by the lowest point above a given temperature. The evaluation is done based on a slice across the burner and normal to the x-direction.

```
# find the slice
slc = sim.slices.get_by_id('BurnerTempX')

# convert it to a global data structure and get the coordinates
slc_data, slc_coords = slc.to_global(masked=True, fill=np.nan, return_coordinates=True)
```

First, the data at a arbitrary point in time is visualsied. The white parts represent the obsticles.

```
# pick a time index
it = slc.get_nearest_timestep(150)

# visualise the data
plt.imshow(slc_data[it,:,:].T, origin='lower', vmax=200, extent=slc.extent.as_list())
plt.title(f'Temperature at t={slc.times[it]:.2f}s')
plt.xlabel('y position / m')
plt.ylabel('z position / m')
plt.colorbar(orientation='horizontal', label=f'{slc.quantity.name} / {slc.quantity.unit}' )

# save output to file
#plt.savefig('figs/appartment_temp_slice.svg', bbox_inches='tight')

plt.close()
```

Now, for each y-position the z-indices are found, where the temperature exceedes the limit temperature. The lowest value is the smoke layer height at the y-position.

```
# set temperature limit
temperature_limit = 75

# create a data array to store the local height values, default
# is the maximal z-coordinate
layer_height = np.full(slc_data.shape[1], slc_coords['z'][-1])

# loop over all indices
for ix in range(len(layer_height)):
    # find indices which exceed the limit
    lt = np.where(slc_data[it, ix, :] > temperature_limit)[0]
    # if there are any, pick the lowest one
```

```
    if len(lt) > 0:
        layer_height[ix] = slc_coords['z'][lt[0]]
```

The resulting values can now be plotted over the slice file, to check for plausibility.

```
# slice data
plt.imshow(slc_data[it,:,:].T, origin='lower', vmax=200, extent=slc.extent.as_list())
plt.title(f'Temperature at t={slc.times[it]:.2f}s')
plt.xlabel('y position / m')
plt.ylabel('z position / m')
plt.colorbar(orientation='horizontal', label=f'{slc.quantity.name} / {slc.quantity.unit}' );

# smoke layer height
plt.plot(slc_coords['y'], layer_height, '.-', color='red')

# save output to file
#plt.savefig('figs/appartment_temp_slice_height.svg', bbox_inches='tight')

plt.close()
```

Using the above approach for a single point in time, a loop over all times can be used to compute, e.g., the mean and standard deviation of the smoke layer height.

```
layer_mean = np.zeros_like(slc.times)
layer_stddev = np.zeros_like(slc.times)

res = np.zeros(slc_data.shape[1])

for it in range(len(slc.times)):

    res[:] = slc_coords['z'][-1]

    for ix in range(len(res)):
        lt = np.where(slc_data[it, ix, :] > temperature_limit)[0]
        if len(lt) > 0:
            res[ix] = slc_coords['z'][lt[0]]

    layer_mean[it] = np.mean(res)
    layer_stddev[it] = np.std(res)
```

```
# plot the mean and stddev values as functions of time
plt.plot(slc.times, layer_mean, label='Mean Smoke Layer Height')
plt.plot(slc.times, layer_stddev, label='Stddev of Smoke Layer Height')
plt.grid()
plt.legend()
plt.xlabel('Time / s')
plt.ylabel('Height / m')

# save output to file
#plt.savefig('figs/appartment_layer_mean_stddev.svg', bbox_inches='tight')

plt.close()
```

Both values can be combined and visualised jointly, where the standard deviation is used to indicate a fluctuation band around the mean value.

```
# plot the mean
plt.plot(slc.times, layer_mean, label='Mean Smoke Layer Height')

# plot a band around the mean, using the stddev as band borders
plt.fill_between(slc.times, layer_mean-layer_stddev, layer_mean+layer_stddev, color='C0', alp

# show the floor for reference
plt.ylim(bottom=0)
plt.grid()
plt.legend()
plt.xlabel('Time / s')
plt.ylabel('Height / m')

# save output to file
#plt.savefig('figs/appartment_layer_mean_band.svg', bbox_inches='tight')

plt.close()
```

If parts of the region shall be excluded in the analysis, a coordinate dependent mask can be used for this.

```
# find indices, where the y coordinate is between the given values
ymin = 1
ymax = 4
coord_mask = np.where((slc_coords['y'] > ymin) & (slc_coords['y'] < ymax))
```

```
# slice data
plt.imshow(slc_data[it,:,:].T, origin='lower', vmax=200, extent=slc.extent.as_list())
plt.title(f'Temperature at t={slc.times[it]:.2f}s')
plt.xlabel('y position / m')
plt.ylabel('z position / m')
plt.colorbar(orientation='horizontal', label=f'{slc.quantity.name} / {slc.quantity.unit}' );

# smoke layer height
plt.plot(slc_coords['y'][coord_mask], layer_height[coord_mask], '.-', color='red')

# save output to file
#plt.savefig('figs/appartment_temp_slice_height_mask.svg', bbox_inches='tight')

plt.close()
```

The above procedure can be reused, yet the computation of the mean and standard deviation is carried out on the masked values.

```
for it in range(len(slc.times)):

    res[:] = slc_coords['z'][-1]

    for ix in np.ndindex(res.shape):
        lt = np.where(slc_data[it, ix, :] > temperature_limit)[1]
        if len(lt) > 0:
            res[ix] = slc_coords['z'][lt[0]]

    # computation is carried out on the masked values now
    layer_mean[it] = np.mean(res[coord_mask])
    layer_stddev[it] = np.std(res[coord_mask])
```

```
# same plot as above
plt.plot(slc.times, layer_mean, label='Mean Smoke Layer Height')
plt.fill_between(slc.times, layer_mean-layer_stddev, layer_mean+layer_stddev, color='C0', alp
plt.ylim(bottom=0)
plt.grid()
plt.legend()
plt.xlabel('Time / s')
plt.ylabel('Height / m')

# save output to file
#plt.savefig('figs/appartment_layer_mean_band_mask.svg', bbox_inches='tight')
```

```
plt.close()
```

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