Import Libraries

In [1]:
```
import numpy as np
import pandas as pd
import datetime
from datetime import datetime
import math

import sys
import os

pd.options.mode.chained_assignment = None

pd.set_option("display.max_rows", None)
pd.set_option("display.max_columns", None)
pd.set_option('display.max_colwidth', None)

import seaborn as sns
import matplotlib.pyplot as plt
import matplotlib.dates as mdates
```

In [2]:
```
np.random.seed(311)
```

Load Data

In [3]:
```
current_file_path = os.path.dirname(os.path.realpath('__file__'))
current_folder_name = 'code'

project_base_path = current_file_path.removesuffix(current_folder_name)
temperature_filepath = project_base_path + '/data/input/temperature data.xls
```

In [4]:
```
temperature_df = pd.read_excel(
    temperature_filepath,
    header = 1
)

temperature_df.head()
```

Out[4]:

	Date	Time	Date/time	Room A	GSW+FM	AFLN+MU	AFLN+FB	AFLH+FM	AFLH+MU
0	2023-02-01	22:00:00	2023-02-01 22:00:00	20.5	15.2	13.3	13.7	15.3	15.6
1	2023-02-01	23:00:00	2023-02-01 23:00:00	20.8	15.2	13.4	13.8	15.4	15.7
2	2023-02-02	00:00:00	2023-02-02 00:00:00	21.0	15.2	13.5	14.0	15.5	15.8
3	2023-02-02	01:00:00	2023-02-02 01:00:00	21.1	15.3	13.5	14.1	15.6	15.8
4	2023-02-02	02:00:00	2023-02-02 02:00:00	21.3	15.3	13.7	14.2	15.7	15.9

In [5]:
```
temperature_df.shape
```

Out[5]:
```
(2154, 36)
```

In [6]:
```
print('Columns:\n')
print(*temperature_df.columns, sep = ' ')
```

```
Columns:

Date Time Date/time Room A GSW+FM AFLN+MU AFLN+FB AFLH+FM AFLH+MU AFLH GSW+
FB AFLN+FM GSW+MU AFLH+FB Room B GSW+MU.1 AFLH.1 AFLH+FB.1 GSW+FM.1 AFLH+M
U.1 AFLN+FM.1 GSW+FB.1 AFLN+FB.1 AFLH+FM.1 AFLN+MU.1 Room C AFLH+FM.2 GSW+F
B.2 GSW+MU.2 AFLN+FM.2 GSW+FM.2 AFLH.2 AFLN+MU.2 AFLN+FB.2 AFLH+FB.2 AFLH+M
U.2
```

Transform Dataframe for organizing blocks(bottles) better

Split dataset into subsets per each block(bottle)

In [7]:
```
temperature_df_subset_A = temperature_df[
    [
        'Date', 'Time', 'Date/time', 'Room A',
        'GSW+FM', 'AFLN+MU', 'AFLN+FB',
       'AFLH+FM', 'AFLH+MU', 'AFLH',
        'GSW+FB', 'AFLN+FM', 'GSW+MU', 'AFLH+FB'
    ]
]

temperature_df_subset_B = temperature_df[
    [
        'Date', 'Time', 'Date/time', 'Room B',
        'GSW+MU.1', 'AFLH.1', 'AFLH+FB.1',
        'GSW+FM.1', 'AFLH+MU.1', 'AFLN+FM.1',
        'GSW+FB.1', 'AFLN+FB.1', 'AFLH+FM.1', 'AFLN+MU.1'
    ]
]
```

```
temperature_df_subset_C = temperature_df[
    [
        'Date', 'Time', 'Date/time', 'Room C',
        'AFLH+FM.2', 'GSW+FB.2', 'GSW+MU.2',
        'AFLN+FM.2', 'GSW+FM.2', 'AFLH.2',
        'AFLN+MU.2', 'AFLN+FB.2', 'AFLH+FB.2', 'AFLH+MU.2'
    ]
]
```

In [8]:
```
temperature_df_subset_A.head()
```

Out[8]:

	Date	Time	Date/time	Room A	GSW+FM	AFLN+MU	AFLN+FB	AFLH+FM	AFLH+MU
0	2023-02-01	22:00:00	2023-02-01 22:00:00	20.5	15.2	13.3	13.7	15.3	15.6
1	2023-02-01	23:00:00	2023-02-01 23:00:00	20.8	15.2	13.4	13.8	15.4	15.7
2	2023-02-02	00:00:00	2023-02-02 00:00:00	21.0	15.2	13.5	14.0	15.5	15.8
3	2023-02-02	01:00:00	2023-02-02 01:00:00	21.1	15.3	13.5	14.1	15.6	15.8
4	2023-02-02	02:00:00	2023-02-02 02:00:00	21.3	15.3	13.7	14.2	15.7	15.9

Transform columns into a common style:

Add a column indicating a block

In [9]:
```
temperature_df_subset_A['Block'] = 'A'
temperature_df_subset_B['Block'] = 'B'
temperature_df_subset_C['Block'] = 'C'
```

Remove block indicator

In [10]:
```
temperature_df_subset_A = temperature_df_subset_A.rename(columns = {'Room A
temperature_df_subset_B = temperature_df_subset_B.rename(columns = {'Room B
temperature_df_subset_C = temperature_df_subset_C.rename(columns = {'Room C
```

Remove digits from column names for treatments

In [11]:
```
def remove_digits_from_column_names(df):
    df.columns = df.columns.str.replace('[\.\d]', '', regex = True)

remove_digits_from_column_names(temperature_df_subset_B)
remove_digits_from_column_names(temperature_df_subset_C)
```

Combine datasets with each block into one

In [12]:
```
temperature_df_transformed = pd.concat([
    temperature_df_subset_A,
```

```
    temperature_df_subset_B,
    temperature_df_subset_C
],
    ignore_index = True
)
```

In [13]:
```
temperature_df_transformed.head(10)
```

Out[13]:

	Date	Time	Date/time	Room	GSW+FM	AFLN+MU	AFLN+FB	AFLH+FM	AFLH+MU
0	2023-02-01	22:00:00	2023-02-01 22:00:00	20.5	15.2	13.3	13.7	15.3	15.6
1	2023-02-01	23:00:00	2023-02-01 23:00:00	20.8	15.2	13.4	13.8	15.4	15.7
2	2023-02-02	00:00:00	2023-02-02 00:00:00	21.0	15.2	13.5	14.0	15.5	15.8
3	2023-02-02	01:00:00	2023-02-02 01:00:00	21.1	15.3	13.5	14.1	15.6	15.8
4	2023-02-02	02:00:00	2023-02-02 02:00:00	21.3	15.3	13.7	14.2	15.7	15.9
5	2023-02-02	03:00:00	2023-02-02 03:00:00	21.4	15.4	13.7	14.3	15.8	16.0
6	2023-02-02	04:00:00	2023-02-02 04:00:00	21.5	15.4	13.8	14.5	15.9	16.1
7	2023-02-02	05:00:00	2023-02-02 05:00:00	21.6	15.5	14.0	14.6	16.0	16.2
8	2023-02-02	06:00:00	2023-02-02 06:00:00	21.7	15.5	14.1	14.7	16.1	16.2
9	2023-02-02	07:00:00	2023-02-02 07:00:00	21.9	15.6	14.2	14.9	16.2	16.3

Data Cleaning

Convert Date to a pandas datetime object

In [14]:
```
temperature_df_transformed['Date'] = pd.to_datetime(
    temperature_df_transformed['Date']
)

temperature_df_transformed['Date/time'] = pd.to_datetime(
    temperature_df_transformed['Date/time']
)
```

Some records have unrealistic values for Date/time

In [15]:
```
temperature_df_transformed['Date/time'].min()
```

Out[15]:
```
Timestamp('1970-01-01 00:00:00.000000045')
```

In [16]:
```
temperature_df_transformed[
    temperature_df_transformed['Date/time'] == temperature_df_transformed['D
].head()
```

Out[16]:

	Date	Time	Date/time	Room	GSW+FM	AFLN+MU	AFLN+FB	AFLH+FM	A
2150	NaT	NaN	1970-01-01 00:00:00.000000045	0.0	68.0	209.0	410.0	435.0	
4304	NaT	NaN	1970-01-01 00:00:00.000000045	0.0	0.0	317.0	529.0	497.0	
6458	NaT	NaN	1970-01-01 00:00:00.000000045	0.0	0.0	210.0	617.0	465.0	

Remove the records with unrealistic or missing values for Date and time

In [17]:
```
n_records_before_cleaning_dates = temperature_df_transformed.shape[0]
```

In [18]:
```
temperature_df_transformed.drop(
    temperature_df_transformed[
        temperature_df_transformed['Date/time'] <= np.datetime64('2000-01-01
    ].index,
    inplace = True
)
```

In [19]:
```
temperature_df_transformed['Date/time'].min()
```

Out[19]:
```
Timestamp('2023-02-01 22:00:00')
```

In [20]:
```
n_records_after_cleaning_dates = temperature_df_transformed.shape[0]
```

In [21]:
```
difference = n_records_before_cleaning_dates - n_records_after_cleaning_date

print(
    f'{difference} rows have been removed'
)
```

```
12 rows have been removed
```

In [22]:
```
print('Columns:\n')
print(*temperature_df_transformed.columns.tolist(), sep = ' ')
```

```
Columns:

Date Time Date/time Room GSW+FM AFLN+MU AFLN+FB AFLH+FM AFLH+MU AFLH GSW+FB
AFLN+FM GSW+MU AFLH+FB Block
```

Column 'Time' is redundant, we can drop it

In [23]:
```
temperature_df_transformed.drop('Time', axis = 1, inplace = True)
```

We don't need the treatments below anymore due to change of requirements.Therefore we can drop them

In [24]:
```
not_needed_treatments = ['AFLH+FM', 'AFLH+FB', 'AFLH+MU', 'AFLH']
```

In [25]:
```
temperature_df_transformed.drop(
    columns = not_needed_treatments,
    inplace = True
)
```

Visualize Temperature

Select treatments to visualize

In [26]:
```
temperature_columns = [
    'GSW+FM', 'GSW+FB', 'GSW+MU',
    'AFLN+FM', 'AFLN+FB','AFLN+MU'
]
```

Add colors indicating each block(bottle)

In [27]:
```
blocks = {'A': 'tab:blue', 'B': 'tab:olive', 'C': 'tab:orange'}
```

Add markers for legend for blocks

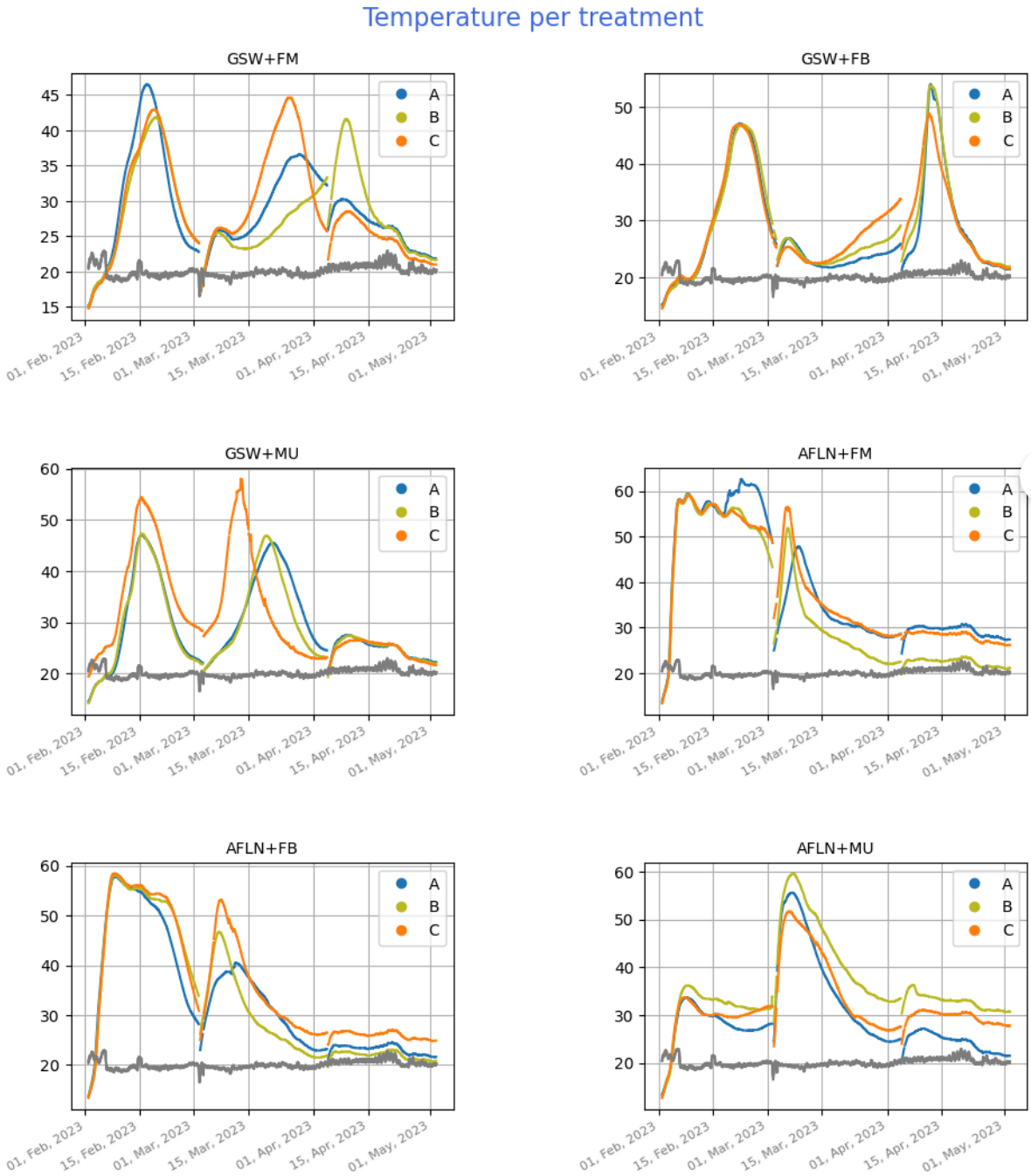
In [28]:
```
markers = [
    plt.Line2D(
        [0,0], [0,0], color = color, marker = 'o', linestyle = ''
    ) for color in blocks.values()
]
```

In [29]:
```
def plot_temperature(df, date_column, column, ax, plot_room_temperature):

    is_room_temperature_plotted = False

    if plot_room_temperature:
        columns = [column, date_column, 'Room']
    else:
        columns = [column, date_column]

    for block_name, color in blocks.items():

        data = df.loc[
            df['Block'] == block_name, columns
        ]

        ax.plot(date_column, column, data = data, color = color)

        if plot_room_temperature and not is_room_temperature_plotted:

            ax.plot(date_column, 'Room', data = data, color = 'tab:gray')

    ax.xaxis.set_minor_locator(mdates.MonthLocator())
    ax.xaxis.set_major_formatter(mdates.DateFormatter('%d, %b, %Y'))

    ax.set_title(column, loc = 'center', fontsize = 'medium')
    ax.set_ylabel('')
    ax.grid(True)
```

```
    for label in ax.get_xticklabels():
        label.set_ha('right')
        label.set_rotation(30.)
        label.set_color('tab:gray')
        label.set_size(8)

    ax.legend(markers, blocks.keys(), numpoints = 1)
```

In [30]:
```
def plot_temperature_for_multiple_columns(
    df,
    date_column,
    title = 'Temperature per treatment',
    plot_room_temperature = True,
    columns = temperature_columns
):
    n = math.ceil(len(temperature_columns) / 2)

    fig = plt.figure(figsize = (11, 4 * n))
    fig.subplots_adjust(hspace = 0.6, wspace = 0.5)

    fig.suptitle(
        title,
        color = 'royalblue',
        fontsize = 16,
        y = 0.93
    )

    for i, col in enumerate(temperature_columns):

        ax = fig.add_subplot(n, 2, i + 1)
        plot_temperature(df, date_column, col, ax, plot_room_temperature)
```

In [31]:
```
plot_temperature_for_multiple_columns(temperature_df_transformed, 'Date/time
```



Parameters for Accumulated Temperature

We transform dataset according to the method described in this research paper:
Thermal Load and Application

Set parameters

In [32]:
```
ROOM_TEMPERATURE = 20
THERMOPHILIC_TEMPERATURE = 45
TEMPERATURE_TO_STERILIZE = 55
```

In [33]:
```
temperature_columns
```

Out[33]:
```
['GSW+FM', 'GSW+FB', 'GSW+MU', 'AFLN+FM', 'AFLN+FB', 'AFLN+MU']
```

Methods for accumulating temperature

1. Calculate the difference between treatment temperature and base (reference) temperature
2. If the treatment temperature is lower than the base (reference) temperature use 0

In [34]:
```
def get_temperature_relative_to_base_temperature(data, column, base_temperat

    return np.where(
        ((data[column] - base_temperature) <= 0),
        0,
        data[column] - base_temperature
    )
```

Calculate mean of the temperature data per day

In [35]:
```
def calculate_mean(data, columns = temperature_columns):

    data = data.groupby(['Block', 'Date'], as_index = False)[columns].mean()
    return data
```

Calculate accumulated(integral) treatment temperature when it has values above the base temperature

In [36]:
```
def get_accumulated_temperature(data, column, base_temperature):

    data['temp_column'] = data[column].cumsum()
    data[column] = data['temp_column']
    data.drop('temp_column', axis = 1, inplace = True)

    return data
```

Calculate accumulated temperature per each block(bottle) and combine subsets together into one dataset

In [37]:
```
def get_accumulated_temperature_for_all_blocks(
    data,
    base_temperature,
    columns = temperature_columns
):
    dfs = []

    block_values = data.Block.unique().tolist()

    for block in block_values:

        data_subset_per_block = data[
            data.Block == block
        ]

        for temp_column in columns:
            data_subset_per_block = get_accumulated_temperature(
                data_subset_per_block, temp_column, base_temperature
            )

        dfs.append(data_subset_per_block)
```

```
    return pd.concat(dfs, ignore_index = True)
```

In [38]:
```
def get_dataset_with_accumulated_temperature(
    data,
    base_temperature,
    columns = temperature_columns,
    need_calculate_mean = True
):
    for col in columns:
        data[col] = get_temperature_relative_to_base_temperature(
            data,
            col,
            base_temperature
        )

    if need_calculate_mean:
        data = calculate_mean(data, columns)
    else:

        selected_columns = ['Block', 'Date', 'Date/time']
        selected_columns.extend(columns)

        data = data[selected_columns]

    data = get_accumulated_temperature_for_all_blocks(data, base_temperature
    return data
```

Accumulated Temperature Based on Room

In [39]:
```
base_temperature = ROOM_TEMPERATURE
```

In [40]:
```
title_with_mean = 'accumulated temperature, with mean'
title_no_mean = 'accumulated temperature, no mean'
```

With mean

In [41]:
```
room_cumulative_temperature_df_with_mean = temperature_df_transformed.copy()
```

In [42]:
```
room_cumulative_temperature_df_with_mean = get_dataset_with_accumulated_temp
    room_cumulative_temperature_df_with_mean,
    base_temperature,
    columns = temperature_columns,
    need_calculate_mean = True
)
```

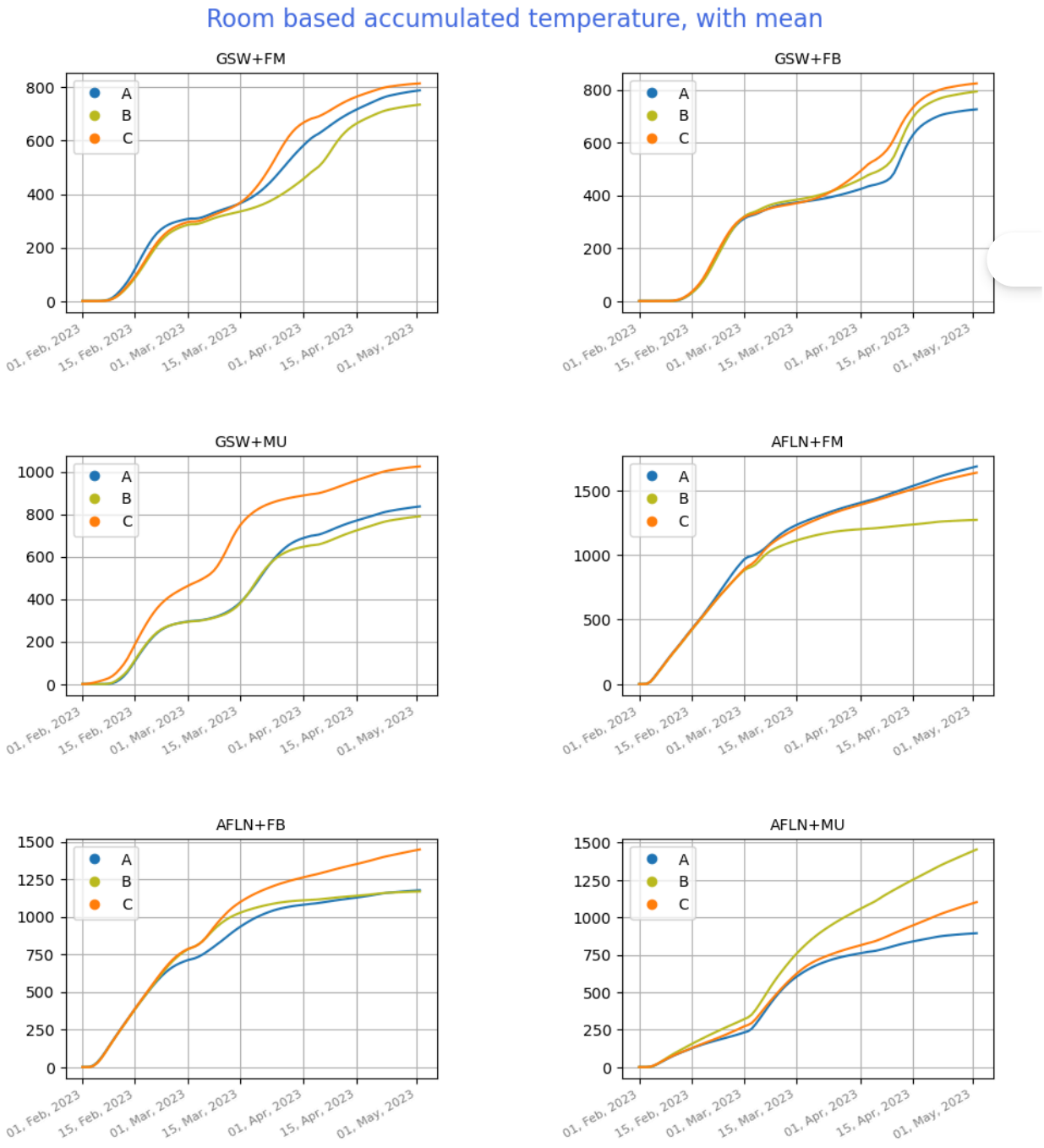
Without mean

In [43]:
```
room_cumulative_temperature_df_no_mean = temperature_df_transformed.copy()
```

In [44]:
```
room_cumulative_temperature_df_no_mean = get_dataset_with_accumulated_tempe
    room_cumulative_temperature_df_no_mean,
    base_temperature,
    columns = temperature_columns,
    need_calculate_mean = False
)
```

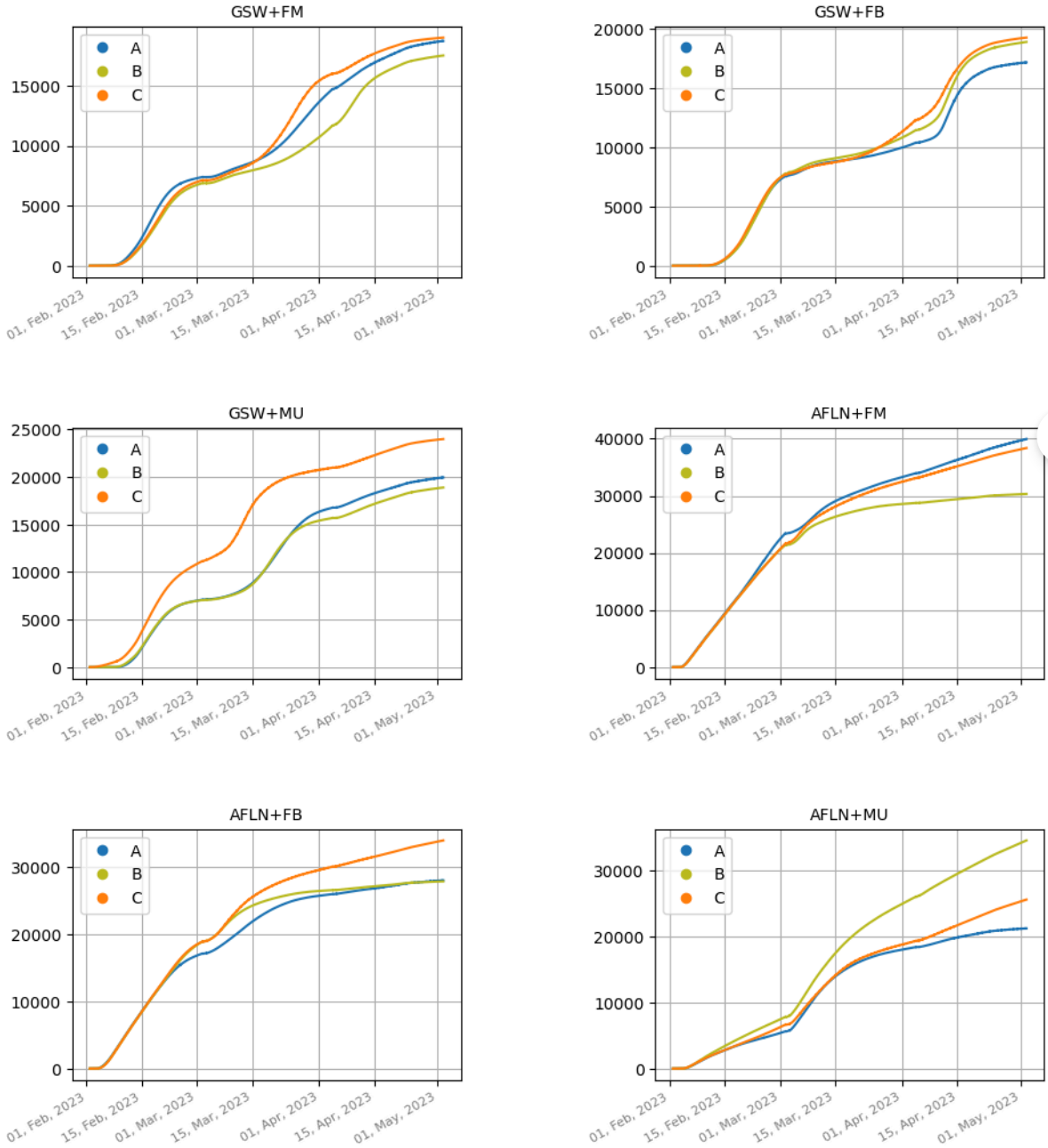
Visualize the accumulated temperature per treatment

In [45]:
```
plot_temperature_for_multiple_columns(
    room_cumulative_temperature_df_with_mean,
    'Date',
    title = 'Room based ' + title_with_mean,
    plot_room_temperature = False
)
```



In [46]:
```
plot_temperature_for_multiple_columns(
    room_cumulative_temperature_df_no_mean,
    'Date/time',
    title = 'Room based ' + title_no_mean,
    plot_room_temperature = False
)
```

Room based accumulated temperature, no mean



Accumulated Temperature Based on Thermophilic

In [47]:
```
base_temperature = THERMOPHILIC_TEMPERATURE
```

In [48]:
```
thermophilic_cumulative_temperature_df_with_mean = temperature_df_transforme
```

In [49]:
```
thermophilic_cumulative_temperature_df_with_mean = get_dataset_with_accumula
    thermophilic_cumulative_temperature_df_with_mean,
    base_temperature,
    columns = temperature_columns,
    need_calculate_mean = True
)
```

In [50]:
```
thermophilic_cumulative_temperature_df_no_mean = temperature_df_transformed
```

In [51]:
```
thermophilic_cumulative_temperature_df_no_mean = get_dataset_with_accumulate
    thermophilic_cumulative_temperature_df_no_mean,
    base_temperature,
```

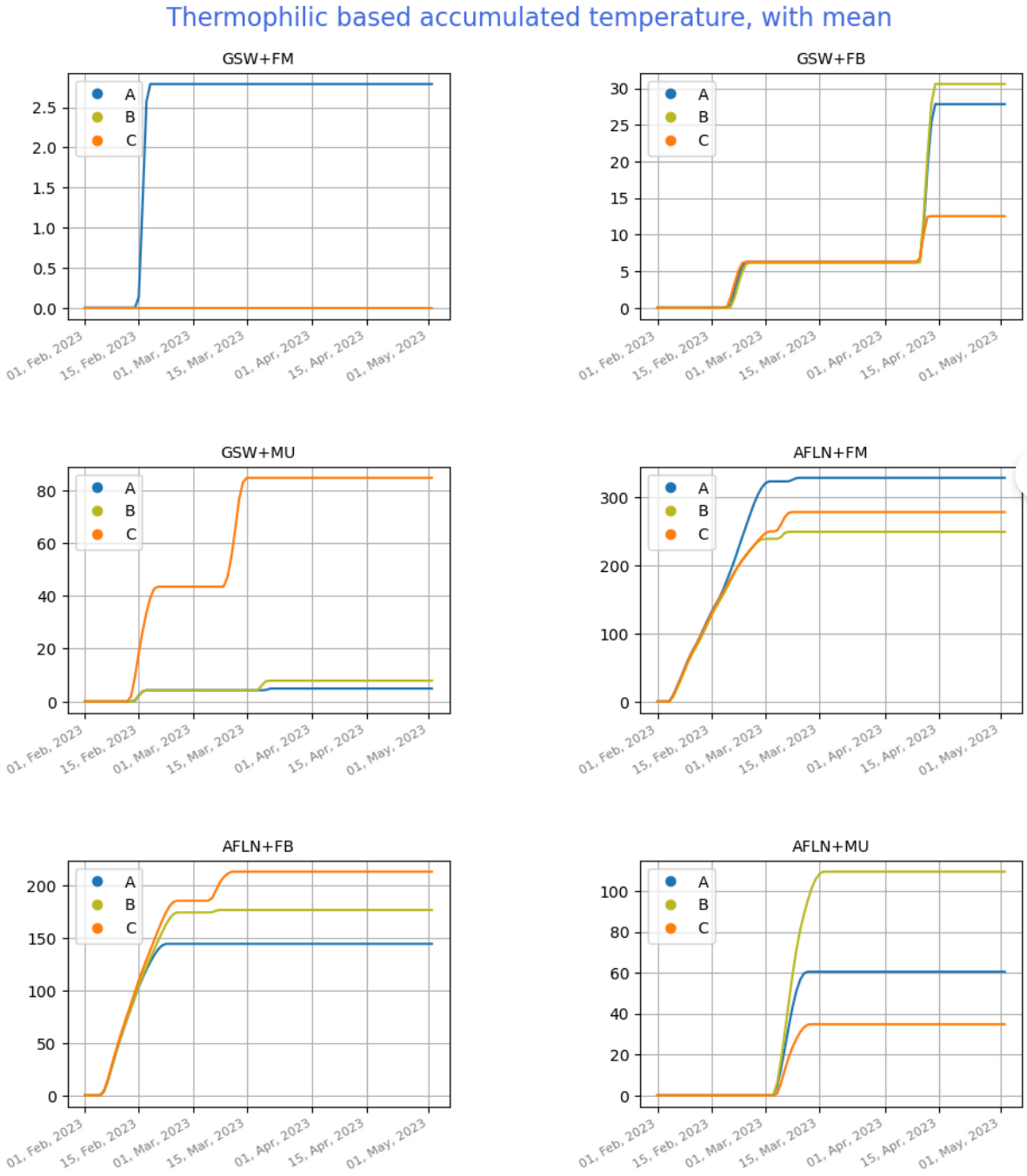
```
    columns = temperature_columns,
    need_calculate_mean = False
)
```

In [52]:
```
thermophilic_cumulative_temperature_df_with_mean.head(10)
```

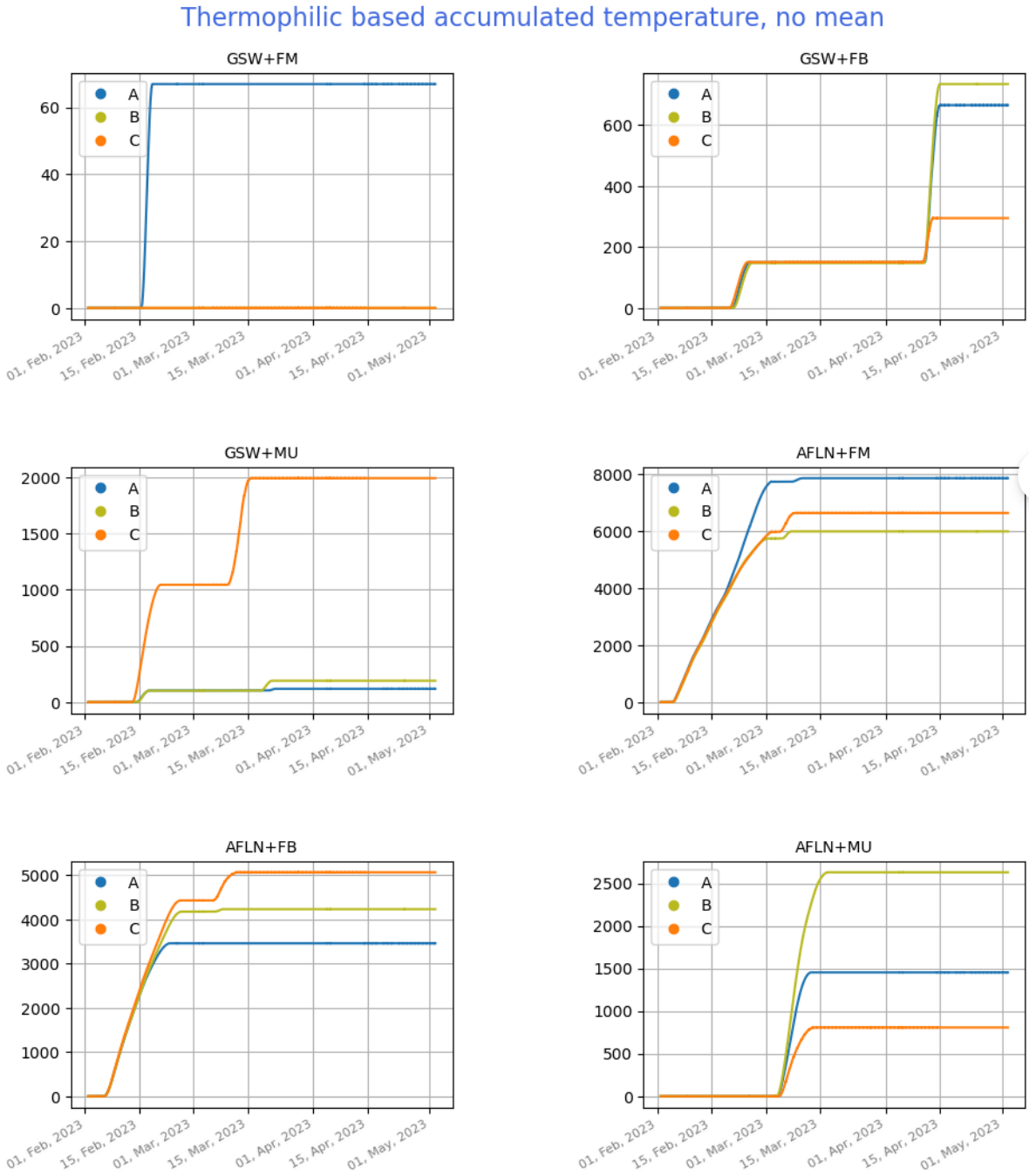
Out[52]:

	Block	Date	GSW+FM	GSW+FB	GSW+MU	AFLN+FM	AFLN+FB	AFLN+MU
0	A	2023-02-01	0.0	0.0	0.0	0.000000	0.000000	0.0
1	A	2023-02-02	0.0	0.0	0.0	0.000000	0.000000	0.0
2	A	2023-02-03	0.0	0.0	0.0	0.000000	0.000000	0.0
3	A	2023-02-04	0.0	0.0	0.0	0.137500	0.000000	0.0
4	A	2023-02-05	0.0	0.0	0.0	8.662500	0.004167	0.0
5	A	2023-02-06	0.0	0.0	0.0	21.725000	4.308333	0.0
6	A	2023-02-07	0.0	0.0	0.0	34.679167	14.345833	0.0
7	A	2023-02-08	0.0	0.0	0.0	48.916667	26.954167	0.0
8	A	2023-02-09	0.0	0.0	0.0	62.379167	39.491667	0.0
9	A	2023-02-10	0.0	0.0	0.0	73.883333	51.300000	0.0

In [53]:
```
plot_temperature_for_multiple_columns(
    thermophilic_cumulative_temperature_df_with_mean,
    'Date',
    title = 'Thermophilic based ' + title_with_mean,
    plot_room_temperature = False
)
```



In [54]:
```
plot_temperature_for_multiple_columns(
    thermophilic_cumulative_temperature_df_no_mean,
    'Date/time',
    title = 'Thermophilic based ' + title_no_mean,
    plot_room_temperature = False
)
```



Accumulated Temperature Based on Sterilize

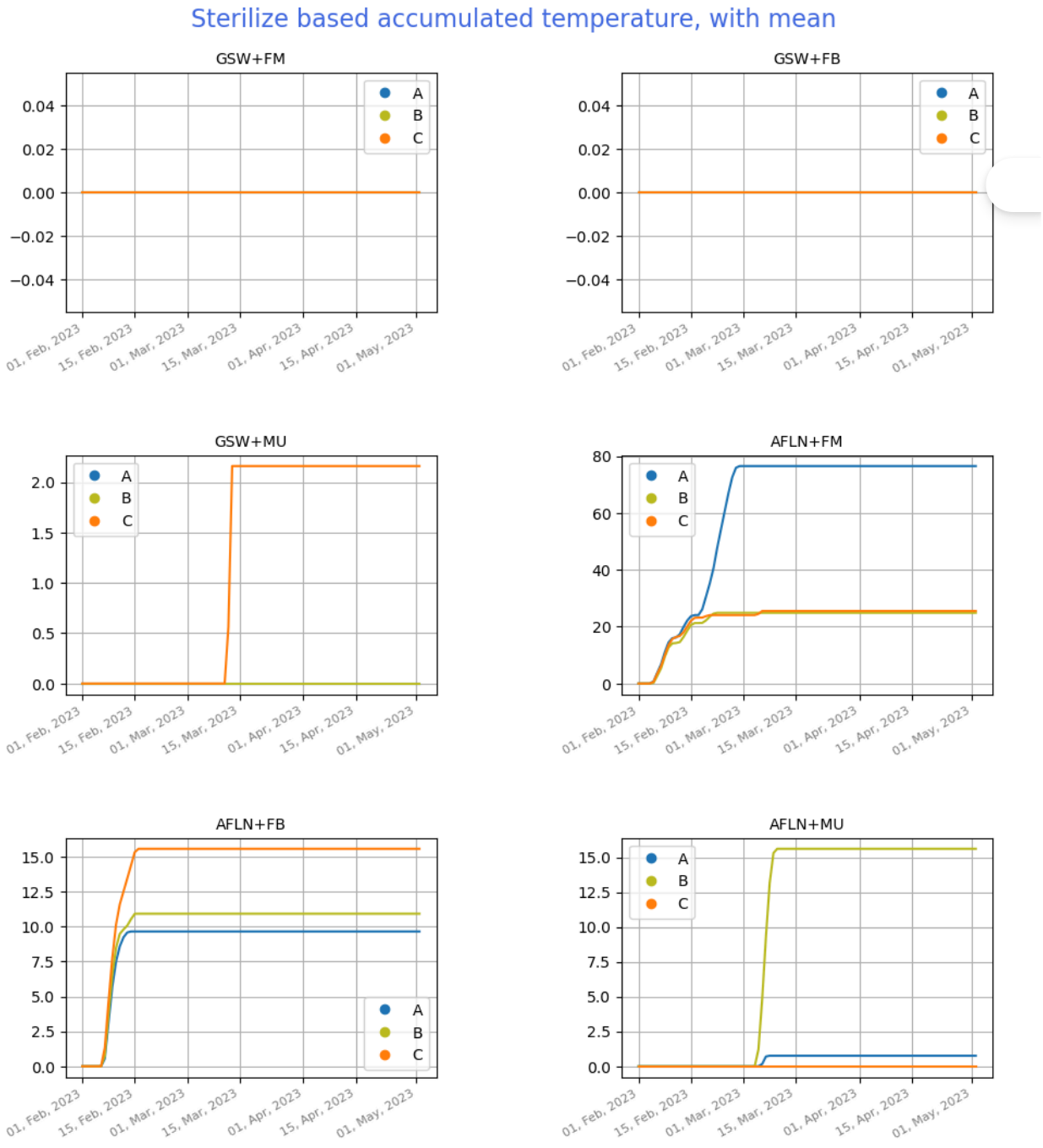
In [55]:
```
base_temperature = TEMPERATURE_TO_STERILIZE
```

In [56]:
```
sterilize_cumulative_temperature_df_with_mean = temperature_df_transformed.c

sterilize_cumulative_temperature_df_with_mean = get_dataset_with_accumulated
    sterilize_cumulative_temperature_df_with_mean,
    base_temperature,
    columns = temperature_columns,
    need_calculate_mean = True
)
```

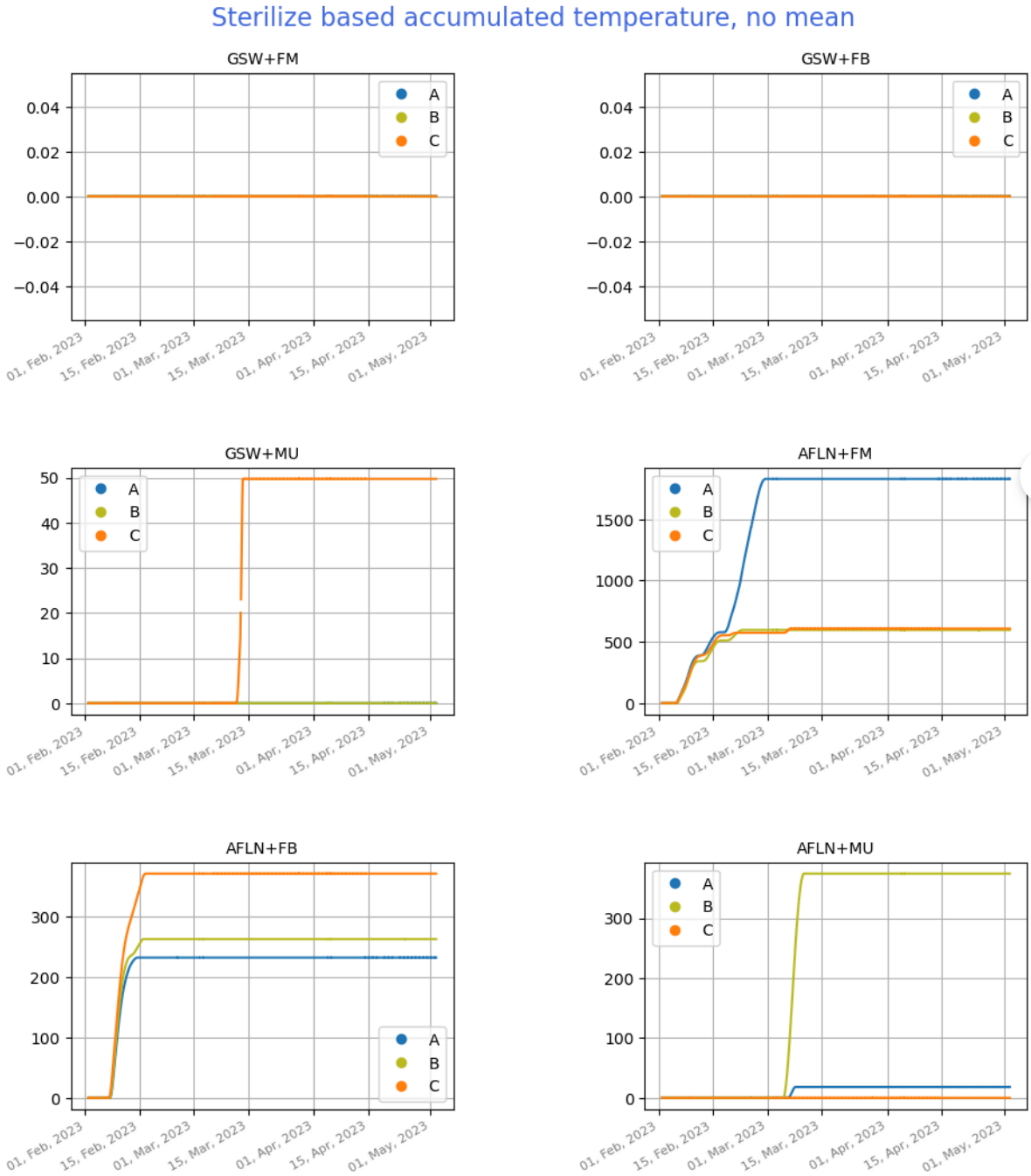
In [57]:
```
sterilize_cumulative_temperature_df_no_mean = temperature_df_transformed.cop

sterilize_cumulative_temperature_df_no_mean = get_dataset_with_accumulated_t
    sterilize_cumulative_temperature_df_no_mean,
    base_temperature,
    columns = temperature_columns,
```

```
    need_calculate_mean = False
)
```

In [58]:
```
plot_temperature_for_multiple_columns(
    sterilize_cumulative_temperature_df_with_mean,
    'Date',
    title = 'Sterilize based ' + title_with_mean,
    plot_room_temperature = False
)
```



In [59]:
```
plot_temperature_for_multiple_columns(
    sterilize_cumulative_temperature_df_no_mean,
    'Date/time',
    title = 'Sterilize based ' + title_no_mean,
    plot_room_temperature = False
)
```



Save data

In [60]:
```
cumulative_temperature_dataframes = {
    'room based cumulative temperature mean.xlsx': room_cumulative_temperatu
    'thermophilic cumulative temperature mean.xlsx': thermophilic_cumulative
    'sterilize cumulative temperature mean.xlsx': sterilize_cumulative_tempe
    'room based cumulative temperature hourly.xlsx': room_cumulative_tempera
    'thermophilic cumulative temperature hourly.xlsx': thermophilic_cumulati
    'sterilize cumulative temperature hourly.xlsx': sterilize_cumulative_ter
}
```

In [62]:
```
output_data_filepath = project_base_path + '/data/output/'
task_filepath = 'Accumulated Temperature Generation in relation to Base/'
```

In [63]:
```
for local_file_path, dataframe in cumulative_temperature_dataframes.items():

    filepath = output_data_filepath + task_filepath + local_file_path
    dataframe.to_excel(filepath, index = False)
```