CIVIL-309: Urban Thermodynamics

Course Project-I: Diagnosis of Urban Thermal Environments

Student Name:

SCIPER Number:

Introduction and instructions:

This project is divided into two parts:

- **Part I** requires you to use the **CityTherm** interactive web tool to analyze the urban thermal environment of a Swiss city. Your goal is to use geospatial data to identify thermal hot and cool spots and diagnose the physical factors that contribute to the differences.

  CityTherm web tool link: `https://citytherm.epfl.ch/`
- **Part II** tests your understanding of the theoretical concepts covered in the lectures 2-4.
- *Evaluation:* The report will be evaluated based on how thoroughly each question is answered and on the correct use of terms and explanations of the phenomena.

Instructions:

1. Answer all questions directly within this interactive PDF document.
   Important: Please download and use the free **Adobe Acrobat Reader** to fill out this PDF. Other PDF viewers, especially those built into web browsers, may not function correctly.
2. For questions requiring a figure (screenshot or plot), please use a PDF editor to insert your image into the designated placeholder box.
3. For fields that require text input, please keep your response within the provided visible space.
4. Save your PDF file frequently
5. Name your final file as follows: ***LASTNAME_SCIPER_CIVIL309_Project I.pdf***
6. Submit your final file on Moodle, **deadline - October 17 at 16:00**

Part I.

Geospatial Analysis with CityTherm

To select the city you will analyze for this project, use *the first letter of your last name*. If your last name begins with a letter **from A to G**, choose **Geneva**. If your last name begins with a letter **from H to Z**, choose **Zurich**. Provide your city in this field:

1. Identifying Thermal Extremes

a) **Site Selection:** In the CityTherm tool, navigate to your chosen city. Activate the **LAND SURFACE TEMPERATURE** (LST) layer. Explore the map to identify three distinct **hot spots** and three distinct **cool spots**. *Note: To focus the analysis on built-up environments, please ensure each selected grid cell has a building land cover fraction greater than 10%.*

Take a screenshot of the LST map showing your six selected locations marked clearly. Insert the screenshot in the box below, and provide numerical values of LST in the table.

b) **Urban Heat Island (UHI) intensity:**

- **Surface UHI:** Calculate the magnitude of the surface UHI using the LST data for your 6 cells. Describe the LST data that would represent the reference rural area.
- **Urban canopy layer UHI:** Using the formula (1-5) from Lecture 1, calculate the maximum nighttime UHI magnitude for all 6 selected cells.

Enter the UHI magnitude values in the table below. Compare the values with your surface UHI magnitudes calculated above.

Insert Screenshot of Your 6 Selected Sites on the LST Map Here
(Use a PDF editor to insert your image)

Location	LST Data (^oC)	Surface UHI (K)	Canopy UHI (K)
Hot Spot 1			
Hot Spot 2			
Hot Spot 3			
Cool Spot 1			
Cool Spot 2			
Cool Spot 3			

Describe how you selected the LST data representing the reference rural area:

Observations: For each of the 6 selected cells, briefly describe your visual observations of the physical environment. *You may activate the **MAP** base layer to better see the city map.*

2. Local Climate Zone (LCZ) Analysis

The Local Climate Zone (LCZ) system classifies urban and rural landscapes into standardized categories based on their form and function.

a) **LCZ Classification:** Activate the **Local Climate Zone (LCZ)** layer. For each of your six selected cells, choose its classification from the dropdown list in the table below.

Location	Cell ID	LCZ Classification
Hot Spot 1		▾
Hot Spot 2		▾
Hot Spot 3		▾
Cool Spot 1		▾
Cool Spot 2		▾
Cool Spot 3		▾

b) **Alignment with Observations in Part (1b):** Do these LCZ classifications align with your visual observations from Part 1b? Provide a brief answer.

3. Quantitative Analysis of Urban Fabric

a) **Land Cover Composition:** For each of the 6 cells, use the **LAND COVER FRACTION** layers to find and record the percentage composition of **Impervious**, **Pervious**, and **Building** surfaces. *Note: the input should be in percentages (%)*

Location	**Buildings (%)**	**Impervious (%)**	**Pervious (%)**	**Water (%)**
Hot Spot 1				
Hot Spot 2				
Hot Spot 3				
Cool Spot 1				
Cool Spot 2				
Cool Spot 3				

b) **Urban Morphology:** Using the **URBAN MORPHOLOGY** layers, provide the values for **Building height (m)**, **Sky view factor (SVF)**, **Aspect ratio**, and **Frontal area index (FAI).**

Location	**Bldg Height (m)**	**SVF (-)**	**Aspect Ratio (-)**	**FAI (-)**
Hot Spot 1				
Hot Spot 2				
Hot Spot 3				
Cool Spot 1				
Cool Spot 2				
Cool Spot 3				

c) **Comparative Analysis:** Based on the data in your tables, describe the key differences in land cover composition and urban morphology between your hot spots and cool spots.

4. Solar Irradiation Analysis

The amount of direct solar energy absorbed by building facades is a critical factor in urban thermal performance. The irradiation layers in CityTherm represent the average direct solar energy received by vertical building walls during summer and winter.

a) **Data Collection:** Return to your six selected hot and cool spots. Using the **IRRADIATION** layers, find and record the total solar energy received on building walls for both seasons in the table below. *Note: The unit is kWh/m*^{2}.

Location	**Summer Irradiation**	**Winter Irradiation**
Hot Spot 1		
Hot Spot 2		
Hot Spot 3		
Cool Spot 1		
Cool Spot 2		
Cool Spot 3		

b) **Thermal Implications:** Analyze the data for your **hot spots**. From a thermal perspective, is the high solar irradiation on building walls a benefit or a liability during the **summer**? Conversely, is it a benefit or a liability during the **winter**? Explain your reasoning for both seasons, considering concepts like solar heat gain and passive heating.

c) **Connection to Urban Form:** Explain how urban morphology (e.g., building density, height, street width) causes the differences in facade irradiation between your hot and cool spots. For instance, do your spots with lower irradiation tend to be in denser areas where buildings provide more mutual shading?

5. Hypothesis and Correlation

a) **Analysis of Morphological Parameters:** Explain the potential effect of each of the 4 urban morphology parameters from Part (3b) on the Land Surface Temperature (LST).

b) **Hypothesis Formulation:** Based on your data and theoretical analysis, identify the **one** morphological variable that you believe shows the **strongest** relationship with LST in your selected spots. Formulate a clear, testable hypothesis about this relationship.
(Example Hypothesis: "A lower Sky View Factor, indicating a more enclosed urban canyon, is hypothesized to cause higher Land Surface Temperatures due to increased longwave radiation trapping.")

c) **Full-Dataset Correlation Analysis:** You will now move from your 6 sample points to a comprehensive analysis using the full dataset provided for your chosen city (Geneva or Zurich). This will allow for a more statistically robust test of your hypothesis.

- **Scatter Plots:** Using a tool like Python, Excel, or Google Sheets, create 4 separate scatter plots. For each plot, the y-axis must be **Land Surface Temperature (LST)**, and the x-axis must be one of the four urban morphology variables from Part 3b. Fit a linear regression trendline to each plot and display the line's equation ($y = mx + c$) and the R-squared value (R^2) on the chart. Arrange the four plots into a single 2x2 grid and insert a screenshot below.

  Python Guide: For this analysis, we recommend using Python. A great way to start without any installation is **Google Colab** (colab.research.google.com). Simply open a new notebook, upload your city's '.csv' file, and use the code snippets below as a guide.

Sample Code: Loading Data Creating Scatter Plots

```
import pandas as pd
import matplotlib.pyplot as plt
import seaborn as sns
from scipy import stats

# 1. Load your data file (make sure you’ve uploaded it to Colab!)
df = pd.read_csv(’your_data_file.csv’)

# 2. It is good practice to simplify column names
df.rename(columns={’LST (°C)’: ’lst_celsius’,
                   ’Sky view factor (-)’: ’svf’}, inplace=True)

# 3. Create the 2x2 grid of scatter plots
morph_vars = [’building_height’, ’svf’, ’aspect_ratio’, ’fai’]
fig, axes = plt.subplots(2, 2, figsize=(14, 11))
axes = axes.flatten() # Flattens the 2x2 grid to a list for easy looping

for i, var in enumerate(morph_vars):
    sns.regplot(x=var, y=’lst_celsius’, data=df, ax=axes[i],
                scatter_kws={’alpha’:0.2}, line_kws={’color’:’red’})
    axes[i].set_title(f’LST vs. {var}’)

plt.tight_layout()
plt.show()
```

Insert 2x2 Grid of Scatter Plots Here

(Use a PDF editor to insert your image)

- **Correlation Heatmap:** To visualize the relationships between multiple variables simultaneously, create a correlation heatmap. The analysis must include the **Land Surface Temperature (LST)** and all eight specified land cover and urban morphology variables:
  - **Land Cover Fraction:** Impervious, Pervious, Water, Building
  - **Urban Morphology:** Building Height, Sky View Factor, Aspect Ratio, Frontal Area Index

  Since the data is not normally distributed, you should use the ***Spearman's rank correlation coefficient (ρ)****. This method checks if a variable consistently increases or decreases as another one does, without requiring the relationship to be a straight line. A value of +1 means they always increase together, -1 means one always decreases as the other increases, and 0 means there is no consistent trend. Insert a screenshot of the final heatmap below.*

Sample Code: Spearman Correlation Heatmap

```
# Define the 9 variables for the heatmap
heatmap_vars = [
    'impervious_fraction', 'pervious_fraction', 'water_fraction',
    'building_fraction', 'building_height', 'svf',
    'aspect_ratio', 'fai', 'lst_celsius'
]
# It's important to drop rows with missing data for this analysis
df_clean = df[heatmap_vars].dropna()

# Calculate the Spearman correlation matrix
correlation_matrix = df_clean.corr(method='spearman')

# Plot the heatmap
plt.figure(figsize=(10, 8))
sns.heatmap(correlation_matrix, annot=True, cmap='coolwarm', fmt='.2f')
plt.title('Spearman Correlation Heatmap')
plt.show()
```

Insert Spearman Correlation Heatmap Here

(Use a PDF editor to insert your image)

- **Interpretation and Validation:** Based on your plots and heatmap from above, answer the following:
  a) Looking at your four scatter plots, does the variable you hypothesized as having the "strongest" effect in question 4b visually appear to be the most correlated with LST? Briefly justify your answer.

  b) From your heatmap, which variable has the highest positive correlation with LST? Which has the highest negative correlation? Do these results support your hypothesis?

6. Thermal Diagnosis

Comprehensive Diagnosis: Select **one** of your identified hot spots (*make sure to provide the corresponding Cell ID*). Provide a concise yet informative summary describing the specific changes or interventions that could be implemented to reduce the Land Surface Temperature (LST) in that area. In your explanation, indicate which environmental or physical phenomena would be influenced by each proposed parameter (e.g., reduced solar radiation absorption, increased street ventilation, etc.).

Part II.
Theoretical Concepts

7. Urban Boundary Layer Structure

The images below illustrate the thermal structure of the Urban Boundary Layer (UBL). Explain in the box below the difference between cases (a) and (b) and when they can be observed.

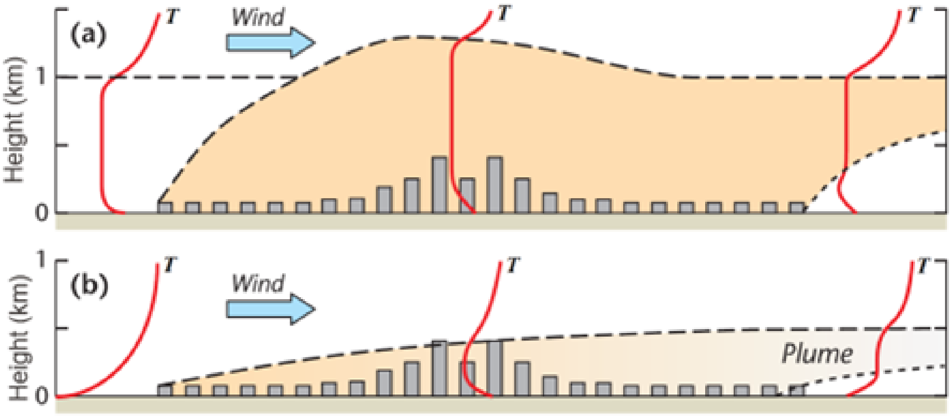


Figure 1: *Thermal structure of the Urban Boundary Layer (UBL)*

8. Energy Flows in the Urban Environment

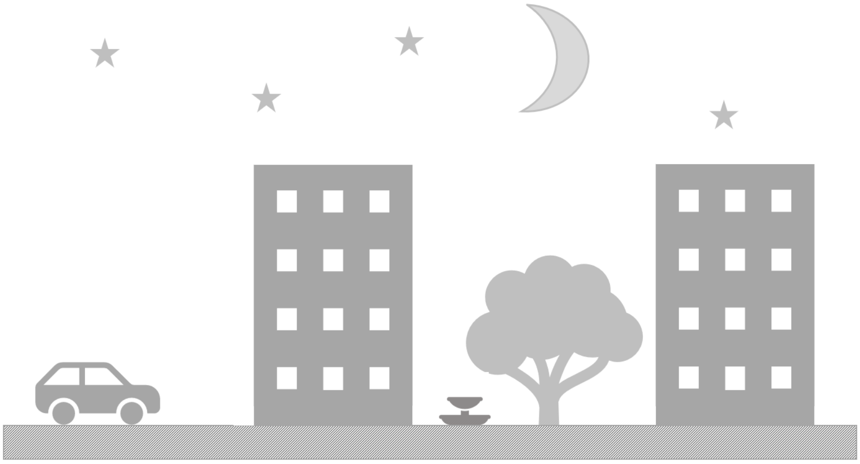
Understanding the flow of heat (fluxes) between urban elements is crucial for urban thermodynamics. **Schematically illustrate these heat flows on the provided diagrams.** Using the drawing/annotation tools in Adobe Acrobat Reader (or similar PDF editor), or even by hand drawing, add arrows and annotations to illustrate the heat fluxes for a shown urban scene during the **daytime** and **nighttime**.

Use arrows to indicate the direction of heat flow and label each arrow with the appropriate abbreviation introduced in the course (Q_H, Q_{cond}, Q_{conv}, Q_E, Q_G, Q_F, ΔQ_S, K, L, S, D). Make sure each arrow is anchored between *the heat source* and *the heat sink* so that the flow of thermal energy is clear.

a) **Daytime Heat Fluxes:**

Annotate directly on the image

b) **Nighttime Heat Fluxes:**



Annotate directly on the image

9. Properties of Urban Materials

The figure shows surface temperatures of urban materials measured during a spring day and night, compared to the average air temperature ($\bar{T}_a$). **Explain the major thermo-physical properties of (a) *the metal surface*, (b) *the brick wall*, and (c) *deciduous trees* that lead to these temperature distributions.**

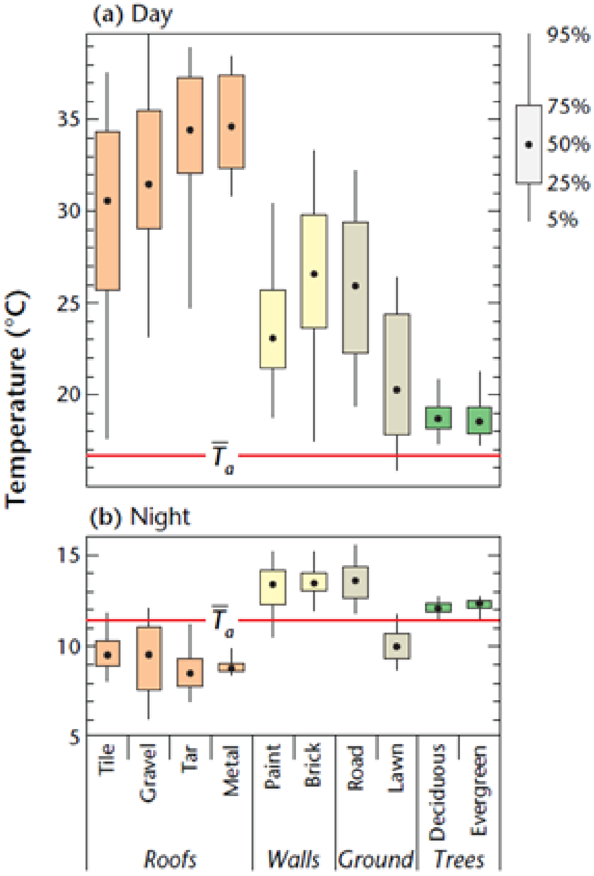


Figure 2: *Boxplot of surface temperatures for various urban materials (a springtime data)*

10. Convection Analysis

Consider a cobblestone pavement shown in the picture below. Its surface reached 70°C while air (dry bulb) temperature was 35°C and the incident solar radiation was $K_\downarrow$ =730 W/m^2 in the afternoon of Aug. 5, 2022. **Determine the rate of convective heat transfer from the surface of the pavement at a wind speed of $u = 4.6$ m/s and compare its magnitude with the value of the incident solar radiation.**

Air properties: density $\rho = 1.084$ kg/m^3, dynamic viscosity $\mu = 19.75 \times 10^{-6}$ (N · s)$/m^2$, thermal diffusivity $\alpha = 25.89 \times 10^{-6}$ m^2/s, thermal conductivity $k = 0.0283$ W/(m·K).

Note: The characteristic length is the width of the pavement, equal to 2 m.

Figure 3: *A cobblestone pavement at the EPFL campus, on Avenue Piccard*

11. Radiation Analysis

Determine **the radiation budget Q^* in W/m^2 at a metal surface** for **an incident irradiance** of $K_\downarrow = 750$ W/m^2. The surrounding environmental temperature (dry bulb temperature) is $30\,°$C, and the surface temperature of the metal is $45\,°$C.

Properties of the surface: albedo (shortwave reflectivity) $\alpha = 0.90$, emissivity $\epsilon = 0.4$

Note: To determine the longwave incident radiation, consider the surrounding environment as a grey body at the environmental temperature, having emissivity typical for urban sites (≈ 0.95).

12. Evaporation Analysis

Consider an urban water surface. At noon (12:00), the net radiative heat flux at the surface is $Q^* = 500\,\text{W/m}^2$, the sensible heat flux is $Q_H = 250\,\text{W/m}^2$, and the latent heat flux is $Q_E = 100\,\text{W/m}^2$. The measured air temperature (dry bulb temperature) is $T_a = 30°\text{C}$, relative humidity is $RH = 42\%$, and average wind speed is $u = 0.6\,\text{m/s}$. Considering the properties provided, **determine the *actual* and *potential* evaporation rates.** As part of your answer, **compare the *radiative* and *aerodynamic* components of the potential evaporation.**

Properties: atmospheric pressure $P = 101.3\,\text{kPa}$; air properties: $\rho_a = 1.164\,\text{kg/m}^3$, $c_p = 1006\,\text{J/(kg}\cdot\text{K)}$; saturation water vapor pressure (at T_a) $p_{v,sat} = 4250\,\text{Pa}$; evaporation parameters: $\gamma = 0.07\,\text{kPa/K}$ and $\Delta = 0.24\,\text{kPa/K}$; latent heat of the vaporization of water $L_v = 2340\,\text{J/kg}$; bulk transfer coefficient for water vapor $C_w = 1.32 \times 10^{-3}$.

— End of Project I —