

CIVIL -309 “Urban Thermodynamics” Course Project 2024

1. Overview

The continuous urban growth presents ongoing and projected challenges to the urban environments and their inhabitants. Changes in urban density, morphology, and materials, along with increased anthropogenic activities, can lead to significant environmental challenges, most notably the urban heat island (UHI) effect, where temperatures within urban areas are higher than in suburban areas, especially during heatwaves. Urban overheating, compounded by ongoing global warming, can cause severe consequences to human life, including thermal discomfort, increased heat-related morbidity and mortality, and increased energy demand. Climate-oriented principles should be incorporated into the planning and design of cities and individual buildings.

This project aims to examine the influence of urban elements on the urban microclimate and thermal energy exchange, investigate their interactions, and explore possible urban overheating mitigation strategies for the given site (*EPFL Innovation Park*).

Three objectives are established for this course project:

1. Critically examine **current site conditions** (e.g., LCZ, material properties, urban morphological parameters, green elements, climate characteristics) in relation to its microclimate;
2. Identify, illustrate, and compare **individual effects** of buildings, ground cover, vegetation, and water on the urban microclimate;
3. Examine the **combined effects of multiple urban elements** on energy exchange and microclimate and propose optimized intervention solutions.

A core component of the project is to explore urban microclimate phenomena and thermodynamic interactions between various urban elements by using a microclimate simulation based on the widely used modelling tool ENVI-met.

By the end of the project, students should be able to:

- Understand the workflow for evaluating the impacts of the urban physical environment on microclimate and human comfort.
- Apply ENVI-met simulation to analyze thermodynamic interactions between various urban elements and inform mitigation solutions.

2. Description of the case study - EPFL Innovation Park

EPFL Innovation Park was established as a community of start-ups, scale-ups, research units, and established tech firms. The site, as shown in Figure 1, is located close to Lake Geneva to its south and in the southwest part of the EPFL campus, adjacent to residential areas on its west and south sides. It features a cluster of rectilinear office buildings, a parking lot, and an urban woodland bordered by roads on three sides. It has an area of around 11 hectares. The ground cover of the site consists of four types of material, including asphalt road, sandy soil, cement concrete pavement, and loam soil (Figure 2a). Building façade and roof materials are detailed in Table 1 and Figure 2(b).

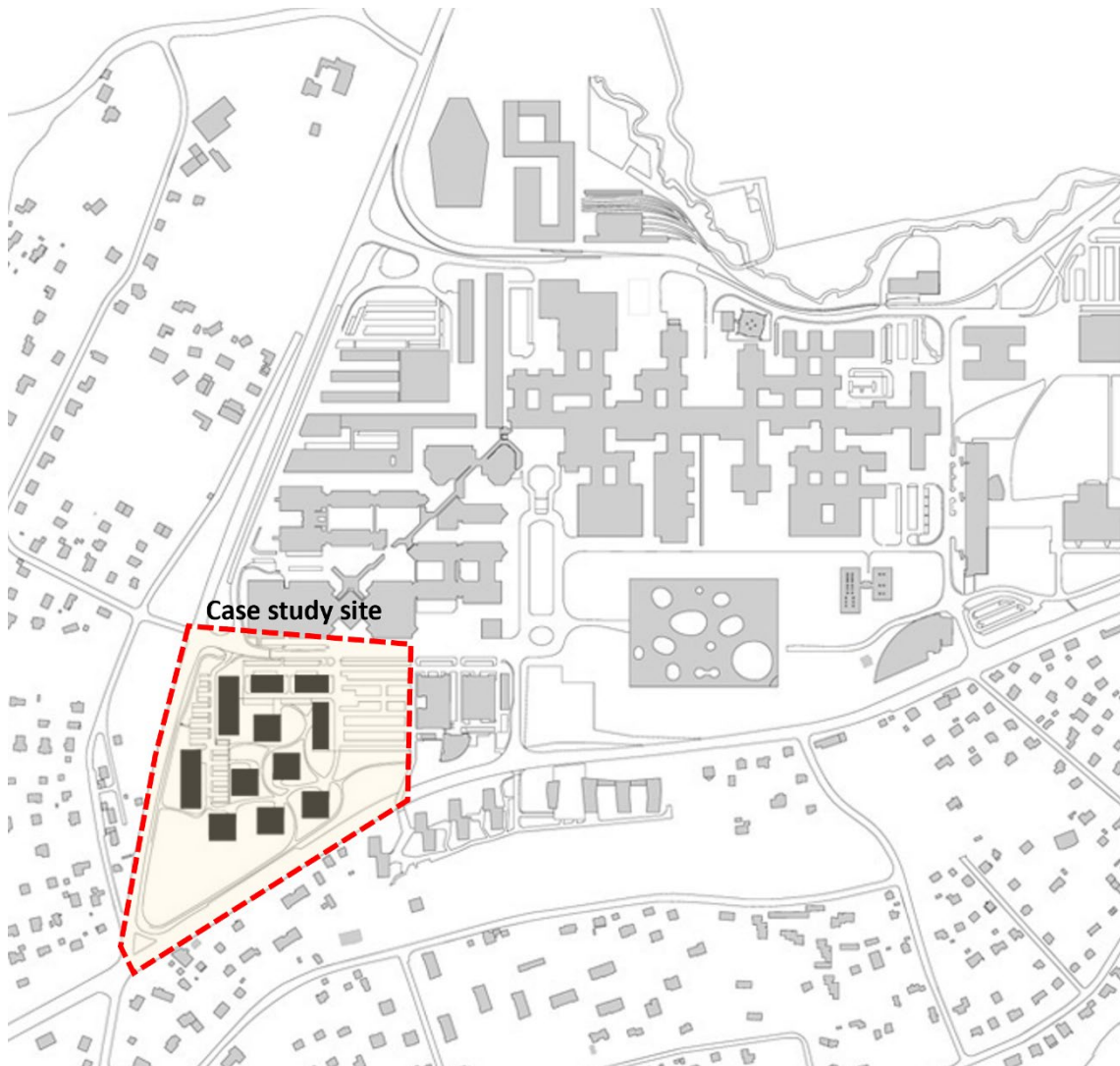


Figure 1. Location of the EPFL Innovation Park on the EPFL campus

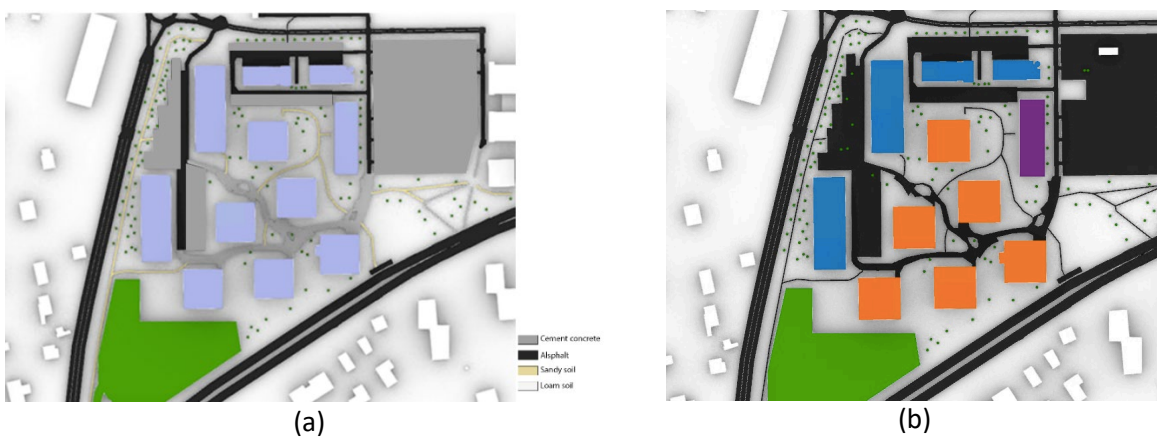


Figure 2. Details of the site: (a) ground cover, (b) building material group (see Table 1 for color coding)

Table 1. Building facade and roof materials (color code of building groups corresponds to Figure 2b)

Category	Layer	Building Group A		Building Group B		Building Group C	
		Material	Thickness (m)	Material	Thickness (m)	Material	Thickness (m)
Façade	1	Prefabricated concrete wall	0.14	Plaster	0.01	Fiber cement board	0.008
	2	Insulation	0.1	EPS Expanded Polystyrene	0.18	Sandwich panel mineral wool	0.15
	3	Plaster	0.047	Plywood (heavyweight)	0.14	Aluminum	0.002
Roof	1	Gravel	0.05	Gravel	0.1	Gravel	0.04
	2	Insulation	0.2	XPS Extruded polystyrene CO2 blow	0.2	Mineral wool insulation	0.08
	3	Reinforced concrete slab	0.3	Concrete reinforced with 2% steel	0.3	Reinforced concrete slab	0.35
	4	--	--	EPS Expanded Polystyrene	0.065	--	--

For this project, weather data in *epw* format from the nearby weather station in *Esplanade* has been chosen. This will be used as a basis for climatic analysis and microclimate simulation. The microclimate simulation utilizes a future climate scenario of *Esplanade* for the year 2100, generated in *Meteonorm*, based on the Representative Concentration Pathway 8.5 as predicted by the Intergovernmental Panel on Climate Change (IPCC).

3. Project structure and project timeline

The project consists of three major components, including site analysis, urban microclimate exploration, and urban mitigation proposal (Figure 3).

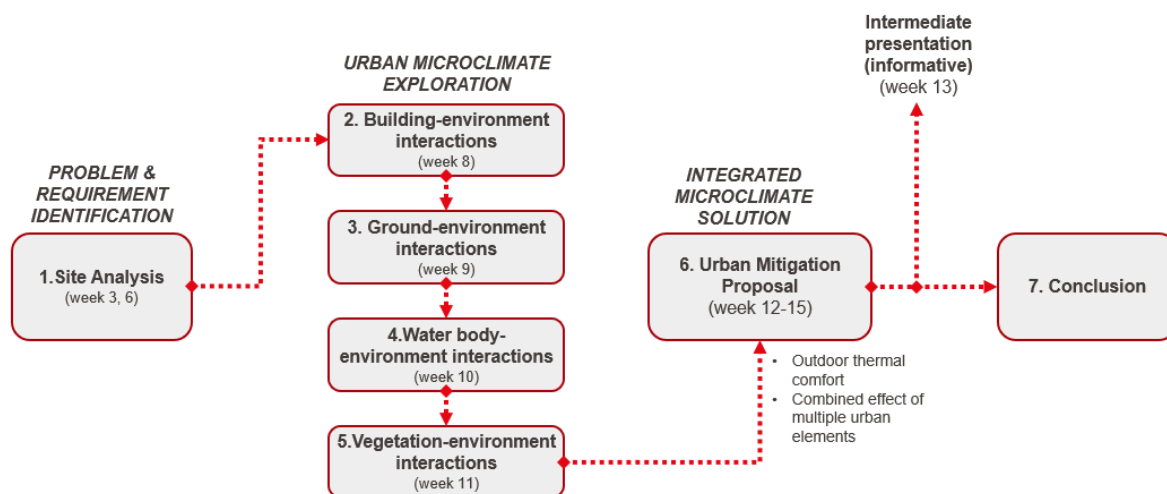


Figure 3 Project structure and timeline.

- **Site analysis:**

Understanding the site conditions is essential for informing the implementation of climate-sensitive strategies in urban design. This part of the project requires students to critically analyze the EPFL innovation park, including its building composition and geometry, materials, green and blue infrastructure, and climatic characteristics. Furthermore, students are required to identify critical environmental conditions (hotspots) on the site and their potential causes through an ENVI-met simulation of the existing conditions. This will inform the proposal of urban heat mitigation strategies.

- **Urban microclimate exploration:**

This part investigates the thermodynamic interactions between various urban elements (building, ground, water, vegetation) for shaping the local climate. Following each week's lecture on thermodynamic interactions (weeks 8–11), the effects of building elements, ground cover, water bodies, and vegetation can be analyzed by comparing two urban scenarios, such as examining the microclimate differences between scenarios with varying building morphology. Reflections on the effectiveness of different measures can inform the final selection of mitigation strategies and relevant parameters for the urban mitigation proposal.

- **Urban mitigation proposal:**

In the *urban mitigation proposal*, an integrated solution to the microclimate problem of the site will be proposed, combining interventions on buildings, ground cover, and green and blue infrastructure (vegetation and water). The effectiveness of the integrated solution will be assessed through individual environmental parameters as well as thermal comfort metrics.

Case Number	Base Case	Building Modification	Ground Modification	Water body Modification	Vegetation Modification	Integrated Solution
Potential modifications	---	Building geometry, wall and roof material, green wall and roof	Ground cover, permeable surface, cool pavement	Fountain, pool, pond (depth, size, shape of water body)	Vegetation type, configuration, green space size and shape	Combined effects, impact on thermal comfort
1	✓					
2	✓	✓				
3	✓		✓			
4	✓			✓		
5	✓				✓	
6	✓	✓	✓	✓	✓	✓

4. Assessment

Assessment of the group work will be done for each component listed below based on the following criteria using a six-point grading scale: **1** (*Inadequate*), **2** (*Needs improvement*), **3** (*Adequate*), **4** (*Proficient*), **5** (*Strong*), and **6** (*Exceptional*).

Project component	Criteria	Expected Deliverables
Site analysis	Site analysis (15%): <i>Demonstrated capacity to critically analysis the site conditions (material, morphology, traffic flow), climate conditions, overheating problem identification and analysis of its contributing factors.</i>	- Climate analysis - Thermal properties of urban surface materials - Urban morphology (sky view factor, building density, aspect ratio) - Simulation results for base case to identify local microclimate issues. The analysis includes air temperature, relative humidity, surface temperature, shortwave & longwave radiation, and wind. Change of environmental parameters across time for specific locations (hotspots).
Urban Microclimate Exploration	Thermodynamic principles (30%): <i>Demonstrated understanding of the thermodynamic principles underlying tested urban scenarios</i>	- Comparisons of microclimate parameters between each intervention and control scenario. - Explanation of the heat exchange processes (energy balance) underlying microclimate differences.
	Mitigation strategies (20%, 5% for each interaction): <i>Demonstrated knowledge and ability to apply UHI mitigation strategies</i>	- Description of each mitigation strategy. - Summary of the mechanism affecting local microclimate and its climate suitability supported by literature (at least two references required for each mitigation strategy).
Integrated Microclimate Solution	Combined effects (15%): <i>interactions of multiple mitigation strategies and their combined effect on microclimate and thermal comfort</i>	- Demonstration of the combined effect of multiple mitigation strategies on microclimate by comparing the <i>integrated solution</i> with previous scenarios. - Examine the impact of the <i>integrated solution</i> on outdoor thermal comfort.
Microclimate Modelling and Analysis	Microclimate simulation and analysis (10%): <i>Ability of conduct simulation and analysis of urban microclimate to general scientific and practical insights</i>	- Outline key settings for simulation. - Rigorous data visualization and analysis.
Report	Written communication (10%)	- Clear and concise written communication of the results. - Appropriate use of scientific terms on urban thermodynamics.

5. Resources:

Access to the computational software ENVI-met

- Students can access licensed ENVI-met software through Virtual Machine via **VDI client** (<https://vdi.epfl.ch/>) server name is «**vdi.epfl.ch**». The pool to use is « **ENAC-ENVIMET** ».
- More information here:
https://support.epfl.ch/epfl?id=epfl_kb_article_view&sysparm_article=KB0017020

Note: At each log in, you will find your data on the VM, but it's not a safe place. Data will be deleted regularly. Save your work on your personal EPFL drive, such as the « Z: » drive or cloud drives.

ENVI-met tutorial

- Overview of the model: <https://www.envi-met.info/doku.php?id=intro:modelconcept>
- Material thermal property value: <https://www.ubakus.de/u-wert-rechner/>
- Selected FAQ:
<https://www.envi-met.info/doku.php?id=kb:start>
<https://www.envi-met.info/doku.php?id=kb:faq>
- Space digitization:
<https://www.youtube.com/watch?v=MttLRxCO9S4>
- ENVI-met data visualization:
 - Guideline document: See file "*Envi-met visualization guide.pdf*"
 - Online tutorial:
[Demo Session | Model Output Visualization Essentials \(youtube.com\)](#)
<https://www.youtube.com/watch?v=TdSUzJ94Kgc&t=230s>