

# CIVIL-309: Urban Thermodynamics

## Course Project-II: Analysis of Urban Mitigation Strategies

### A. Project Description:

**Overview:** This project involves analyzing a pre-computed dataset from a series of 24-hour *ENVI-met microclimate simulations* designed to evaluate various urban mitigation strategies. The core task is a comparative analysis in which the thermal performance of each mitigation scenario is contrasted with an **idealized baseline case (S0)**. The baseline consists of a 4x4 building grid with standard materials, representing a typical Open Mid-Rise (LCZ 5) environment. Each mitigation scenario systematically modifies a *single parameter* from the baseline — such as building height, street material, or vegetation introduction — allowing for a direct investigation of its specific impact. Your analysis must focus on quantifying and explaining the observed differences in key microclimate variables relative to the baseline, while applying the theoretical concepts from the course lectures to interpret the results. **Table 1** outlines the groups of various scenarios provided, while the detailed descriptions of each scenario are provided in **Table 2**. **Sections B, C, and D** provide a more detailed description of the simulation setup, weather conditions, and specific properties considered.

**Simulation Tool and Data Access:** All simulation data is available on the CityTherm interactive web tool, which also allows visualization of spatial data (contour plots) and the extraction of 24-hour time series data for specific points. **Weblink:** <https://citytherm.epfl.ch/simulation/> (needs a connection to EPFL's VPN if used outside the campus).

Table 1: Summary of various groups of analysis and scenarios.

Analysis Groups	Mitigation Category	Scenarios
<b>Building-Environment Analysis (S1 - S2)</b>	<i>Urban Form (S1) and Building Materials (S2)</i>	<i>urban form</i> - S1.1, S1.2, S1.3; <i>building materials</i> - S2.1, S2.2, S2.3
<b>Ground-Environment Analysis (S3)</b>	<i>Ground Modification</i>	S3.1, S3.2, S3.3
<b>Vegetation-Environment Analysis (S4)</b>	<i>Vegetation Strategies</i>	S4.1, S4.2, S4.3
<b>Water-Environment Analysis (S5)</b>	<i>Water Bodies</i>	S5.1, S5.2, S5.3
<b>Combined Effects Analysis (S6)</b>	<i>Integrated Mitigation Proposal</i>	S6.1, S6.2, S6.3, S6.4, S6.5, S6.6

Table 2: Summary of simulation scenarios with detailed description of the main features and what to focus on.

Sim. ID	Scenario Category	Description and Key Variables	Primary Analysis Focus	Relevant Lectures
S0	<b>Baseline</b>	Aligned grid of 4x4 buildings (LCZ 5). Building height - 16 m, street width - 16 m. Urban canyon aspect ratio - 1. Concrete buildings, asphalt ground. No vegetation, no water features.	Establish reference for fluxes, environmental conditions, and comfort metrics.	L1, L6, L7
<b>Group 1: Urban Form</b>				
S1.1	Tall Canyon	Aligned grid of 4x4 buildings. <b>Building height - 30 m</b> , street width - 16 m. Concrete buildings, asphalt ground. No vegetation.	Impact of Urban Canyon Aspect Ratio, Sky View Factor (SVF), mutual shading, and wind flow on canyon climate.	L1, L6
S1.2	Wide Canyon	Aligned grid of 4x4 buildings. Building height - 16 m, <b>street width - 30 m</b> . Concrete buildings, asphalt ground. No vegetation.	Impact of lower Urban Canyon Aspect Ratio, higher SVF, and increased solar access on surface heating.	L1, L6
S1.3	Staggered Layout	<b>Staggered grid</b> of 4x4 buildings. Building height - 16 m, street width - 16 m. Concrete buildings, asphalt ground. No vegetation.	Changes in wind channeling and ventilation in canyons, surface temperatures.	L1, L6
<b>Group 2: Building Materials</b>				
S2.1	Painted Façades	Aligned grid of 4x4 buildings. Building height - 16 m, street width - 16 m. <b>Building façade surface - white paint</b> (roof is concrete); asphalt ground. No vegetation.	Effect of shortwave and longwave radiation, surface temperatures.	L3, L6
S2.2	Glass Façades	Aligned grid of 4x4 buildings. Building height - 16 m, street width - 16 m. <b>Building façade material - glass</b> (roof is concrete); asphalt ground. No vegetation.	Effect of shortwave and longwave radiation, heat storage, surface temperatures.	L3, L6

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Sim. ID	Scenario Category	Description and Key Variables	Primary Analysis Focus	Relevant Lecture(s)
S2.3	Green Façades	Aligned grid of 4x4 buildings. Building height - 16 m, street width - 16 m. <b>Building façade - green walls</b> (roof is concrete); asphalt ground. No vegetation on the ground.	Cooling from evapotranspiration ( $Q_E$ ), surface temperatures, and longwave radiation.	L3, L4, L6, L9
<b>Group 3: Ground Modification</b>				
S3.1	Light Concrete	Aligned grid of 4x4 buildings. Building height - 16 m, street width - 16 m. Concrete buildings, <b>ground - light concrete</b> . No vegetation.	Effect of albedo on surface temperature, radiation balance ( $Q^*$ ), and stored heat ( $\Delta Q_S$ ).	L3, L7
S3.2	Sandy Loam Ground	Aligned grid of 4x4 buildings. Building height - 16 m, street width - 16 m. Concrete buildings, <b>ground - sandy loam soil</b> . No vegetation.	Impact of changing from impervious to pervious surface, allowing for cooling from evapotranspiration ( $Q_E$ ), ground temperatures at different levels.	L3, L7
S3.3	Grass Cover	Aligned grid of 4x4 buildings. Building height - 16 m, street width - 16 m. Concrete buildings, <b>ground - grass (h=25 cm)</b> .	Impact of a low, continuous vegetative cover on surface temperature and latent heat flux ( $Q_E$ ).	L7, L9
<b>Group 4: Vegetation Strategies</b>				
S4.1	Hedges	Aligned grid of 4x4 buildings. Building height - 16 m, street width - 16 m. Concrete buildings, asphalt ground. <b>Vegetation - hedges (h=1 m) along the streets</b> .	Effects of low, dense vegetation on near-ground wind flow, shading, and local humidity.	L4, L9
S4.2	Trees (Betula)	Aligned grid of 4x4 buildings. Building height - 16 m, street width - 16 m. Concrete buildings, asphalt ground. <b>Vegetation - deciduous trees (Betula species) along the streets</b> .	Effect of shading and evapotranspiration from tree canopies on canyon climate.	L4, L9

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Sim. ID	Scenario Category	Description and Key Variables	Primary Analysis Focus	Relevant Lecture(s)
S4.3	Trees (Acer)	Aligned grid of 4x4 buildings. Building height - 16 m, street width - 16 m. Concrete buildings, asphalt ground. <b>Vegetation - deciduous trees (Acer species) along the streets.</b>	Effect of shading and evapotranspiration from tree canopies on canyon climate.	L4, L9
<b>Group 5: Water Bodies</b>				
S5.1	Mist Nozzles	Aligned grid of 4x4 buildings. Building height - 16 m, street width - 16 m. Concrete buildings, asphalt ground. No vegetation, <b>water feature - an active misting/spray system at 3 m height along the buildings.</b>	Intensive, localized evaporative cooling; impact on air temperature and humidity.	L4, L8
S5.2	Water Fountains	Aligned grid of 4x4 buildings. Building height - 16 m, street width - 16 m. Concrete buildings, asphalt ground. No vegetation, <b>water feature - a water fountain (h=4 m) along the buildings.</b>	Cooling from evaporation and the effect of water's high thermal inertia.	L4, L8
S5.3	Water Reservoirs	Aligned grid of 4x4 buildings. Building height - 16 m, street width - 16 m. Concrete buildings, asphalt ground. No vegetation, <b>water feature - water reservoirs at the ground level along the buildings.</b>	Cooling from evaporation and the effect of water's high thermal inertia.	L4, L8
<b>Group 6: Combination Scenarios</b>				
S6.1	Holistic Nature Based Solutions	<b>Combines S1.3 (Staggered) + S2.3 (Green Façades) + S3.3 (Grass) + S4.2 (Trees Betula) + S5.3 (Water Reservoir).</b>	Synergistic cooling from multiple nature-based solutions (evapotranspiration, shading) combined with enhanced ventilation from urban form.	L1, L3, L4, L6, L7, L8, L9

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Sim. ID	Scenario Category	Description and Key Variables	Primary Analysis Focus	Relevant Lecture(s)
S6.2	Cool Technologies	Combines S1.3 (Staggered) + S2.1 (Painted Façades) + S3.1 (High Albedo Pavement) + S5.1 (Mist Nozzles).	Synergistic impact of high-albedo surfaces (reducing $Q^*$ ) and active evaporative cooling (misting), enhanced by improved ventilation.	L1, L3, L4, L6, L7, L8
S6.3	Green & Cool	Combines S2.1 (Painted Façades) + S3.1 (High Albedo Pavement) + S4.3 (Trees Acer). Baseline S0 form.	Interaction of albedo and shading. Comment on "cool" surfaces and tree shading, i.e. whether they complement each other, or if shading negate the albedo effect.	L3, L4, L6, L7, L9
S6.4	Urban Oasis	Combines S3.3 (Grass Cover) + S4.2 (Trees Betula) + S5.2 (Water Fountains). Baseline S0 form.	Impact of maximized localized evaporative cooling. Tests the trade-off between significantly lower $T_{air}$ and potentially very high humidity.	L4, L7, L8, L9
S6.5	Wide & Green	Combines S1.2 (Wide Canyon) + S2.3 (Green Façades) + S4.3 (Trees Acer).	This scenario analyzes whether extensive greening (walls, trees) can mitigate the increased solar access and heating from a wide canyon (S1.2).	L1, L3, L4, L6, L9
S6.6	Deep & Green	Combines S1.1 (Tall Canyon) + S2.3 (Green Façades) + S3.3 (Grass Cover).	This scenario assesses whether green surfaces (walls, ground) can compensate for the reduced ventilation and heat trapping of a deep canyon (S1.1).	L1, L3, L4, L6, L7, L9

(!) Note that the analysis of all scenarios requires human comfort analysis from lecture L10.

## B. Simulation Domain, Boundary, and Forcing Conditions

The simulation setup in ENVI-met employs specific boundary conditions to define how external atmospheric influences interact with our domain:

- **Computational Domain:** The simulation domain is a 3D box, as shown in Figure 1, where atmospheric processes (wind flow, heat, moisture transport, and radiation) are calculated. It includes a central array of buildings and surrounding empty space to allow for the development of realistic atmospheric boundary layers.
- **Constant Wind Input:** Wind is introduced from one side of the domain (the "inlet") with a fixed speed of 2.0 m/s and a direction of  $0^\circ$  from North, as illustrated in Figure 1, throughout the 24-hour simulation. This "*simple forcing*" ensures a consistent and controlled airflow for comparative analysis, allowing us to isolate the effects of other mitigation strategies.
- **Forced Meteorological Data:** Other key atmospheric variables, described in Section C, specifically ambient air temperature, relative humidity, and incoming shortwave and longwave radiation, are "*forced*" into the domain. This means their values at the domain's boundaries are continuously updated based on realistic 24-hour profiles from a Typical Meteorological Year (TMY) weather file for Lausanne. This ensures the simulation accurately reflects realistic diurnal cycles for these parameters.
- **Open Outflow Boundaries:** The remaining three lateral sides of the domain (East, South, West) act as "*open outflow boundaries*," allowing air to exit the simulated area without artificial reflection or recirculation. This mimics natural atmospheric flow and prevents unwanted numerical artifacts at the domain edges.

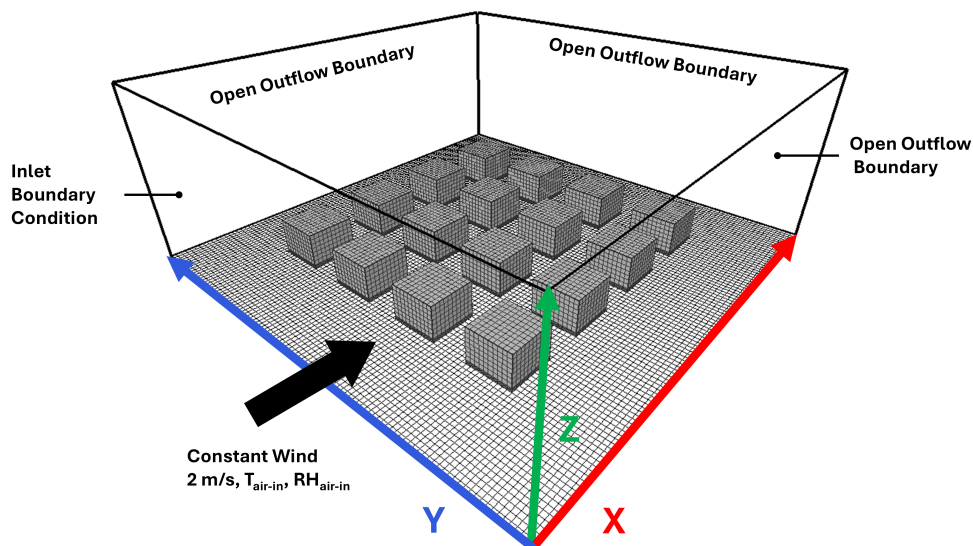


Figure 1: Illustration of the ENVI-met simulation domain, depicting the constant wind input from the North and the open outflow boundaries on the other sides. The text also indicates that temperature, humidity, and radiation are dynamically forced from external meteorological data.

## C. Overview of weather conditions used in simulation scenarios

Typical Meteorological Year (TMY) weather data for Lausanne (specifically for **July 1, 2016**) were used in the simulations. Figure 2 illustrates the daily variation of the main parameters: air temperature, relative humidity, and horizontal shortwave and longwave radiation. Wind velocity, as described in Section B, was imposed as a constant of 2 m/s at the inlet boundary condition.

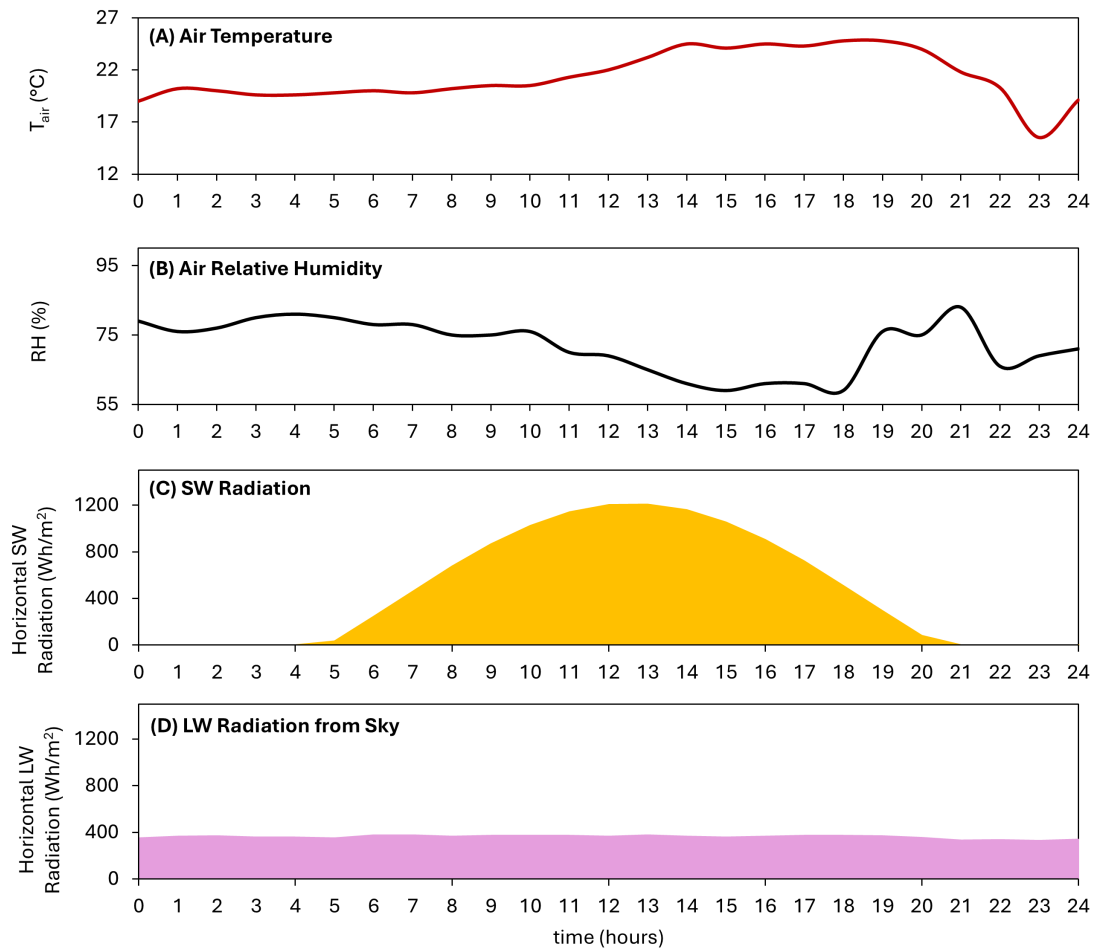


Figure 2: Overview of weather parameters: (A) Air temperature (°C), (B) Relative humidity (%), (C) Total shortwave solar radiation, horizontal (Wh/m<sup>2</sup>), and (D) Longwave radiation from sky, horizontal (Wh/m<sup>2</sup>).

## D. Simulation Parameters and Material Properties

This section details the specific parameters used for various materials and elements within the ENVI-met simulations, based on the scenarios described in Table 2. Where applicable, properties are compared against the Baseline (S0) scenario.

Table 3: Properties of Ground Materials

Scenario / Material	Albedo	Emissivity	Transmittance	Other properties
<b>S0 Asphalt (baseline)</b>	0.12	0.90	0	Roughness length $z_0=0.01$ m
<b>S3.1 Light Concrete</b>	0.50	0.90	0	Roughness length $z_0=0.01$ m
<b>S3.2 Sandy Loam</b>	0.3	0.95	0	Roughness length $z_0=0.015$ m
<b>S3.3 Grass Cover</b>	0.20	0.97	0.3	Plant height 0.25 m, LAD 0.3.

Table 4: Optical Properties of Building Façades (only outer layers)

Scenario / Façade Type	Absorptivity (SW)	Reflectivity (SW)	Transmissivity (SW)	Emissivity
<b>S0 Baseline (Outer Plaster)</b>	0.60	0.40	0	0.93
<b>S2.1 Painted Façade (White Paint)</b>	0.20	0.80	0	0.93
<b>S2.2 Glass Façade (Single-Pane Clear)</b>	0.05	0.05	0.9	0.9
<b>S2.3 Green Façade (Plant foliage)</b>	0.80	0.20	0	0.97

Note: For scenario S2.3 (green façade), plant properties are given.

Table 5: Key Features of S2.3 Green Façade System

Feature	Description / Property
<b>Greening Coverage</b>	0.3 m
<b>Substrate Layer</b>	10 cm sandy loam (albedo 0.3, emissivity 0.95)
<b>Insulation Layer</b>	5 cm styrofoam
<b>Air Gap</b>	0.2 m between substrate and wall

Table 6: General Properties of Plants

Scenario / Plant Type	Height (m)	Diam. (m)	$\alpha$	$\epsilon$	$\tau$	LAI	LAD
<b>S2.3 Plant - <i>Funika</i></b>	0.3	n/a	0.20	0.97	0.30	1.5	0.15
<b>S3.3 Grass - <i>aver</i></b>	0.25	n/a	0.20	0.97	0.30	2.0	0.3
<b>S4.1 Hedges - <i>dense</i></b>	1.0	n/a	0.20	0.97	0.30	1.0	1.0
<b>S4.2 Tree - <i>Betula</i></b>	6.0	7.0	0.18	0.96	0.30	4.0	0.8
<b>S4.3 Tree - <i>Acer</i></b>	11.0	9.0	0.50	0.96	0.30	5.0	0.7

\*  $\alpha$  (Albedo),  $\epsilon$  (Emissivity),  $\tau$  (Transmittance), LAI (Leaf Area Index,  $m^2/m^2$ ), LAD (Leaf Area Density,  $m^2/m^3$ ).

Table 7: Thermophysical Properties of Building and Ground Materials

Category	Layer (Thickness)	$k$ (W/m·K)	$C_p$ (J/kg·K)	$\rho$ (kg/m <sup>3</sup> )	$C_{vol}$ (MJ/m <sup>3</sup> ·K)
<b>Building Surfaces</b>					
<b>Wall Construction (S0, etc.)</b>	Plaster (1 cm)	0.60	850	1500	1.28
	+ Insulation (12 cm)	0.07	1500	400	0.60
	+ Concrete (18 cm)	1.60	850	2220	1.89
<b>Glass Construction (S2.2)</b>	Glass (single pane)	1.05	750	2500	1.88
<b>Ground Surfaces</b>					
<b>Asphalt (S0)</b>	Asphalt (30 cm)	0.90	969	2322	2.25
	Sandy Loam (30-200 cm)	0.50	880	1500	1.32
<b>Sandy Loam (S3.2)</b>	Sandy Loam (200 cm)	0.50	880	1500	1.32
<b>Light Concrete (S3.1)</b>	Cement Concrete (4 cm)	1.63	867	2400	2.08
	Sand (4-6 cm)	0.80	730	2000	1.46
	Sandy Loam (6-200 cm)	0.50	880	1500	1.32

Note: Volumetric Heat Capacity ( $C_{vol}$ ) is  $C_p \times \rho$ . Values for ground  $C_p$  are calculated from the provided  $C_{vol}$  and  $\rho$ .

Table 8: Detailed Biomechanical Properties of Tree Species

Scenario / Tree Species	Leaf Weight [g/m <sup>2</sup> ]	Root Diame- ter [m]	Root [m]	Depth	Wood Den- sity [kg/m <sup>3</sup> ]
<b>S4.2 Tree - <i>Betula Pendula</i></b>	100.0	10.0	1.40		590.0
<b>S4.3 Tree - <i>Acer Negundo</i></b>	100.0	10.0	2.00		590.0

Table 9: Characteristics of Water Features

Scenario / Water Feature	Type	Release Height (m)	Direction	Flow Rate/cell (g/s)
<b>S5.1 Misting System</b>	Active spray	3.0	Down	5.0 (constant 24h)
<b>S5.2 Water Fountain</b>	Active spray	0 → 4.0	Up	5.0 (constant 24h)
<b>S5.3 Water Reservoir</b>	Deep water body	n/a	n/a	n/a

Note on S5.3 Water Reservoir: This passive feature is defined by its surface properties (Roughness  $z_0=0.01\text{m}$ ,  $\epsilon=0.9$ ). Ground balance does not account for direct solar exchange; temperature development may be underestimated.

## ===== REPORT INSTRUCTIONS =====

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**Project Workflow:** The project is divided into individual analysis tasks, followed by collaborative work. **Table 2** provides a detailed description of all scenarios. Each student should select **the most effective mitigation scenario** from their group (e.g., S1, S2, S3, S4, or S5) and conduct a thorough analysis of its performance relative to the baseline scenario (S0). The team should select one of the scenarios within the S6 group and conduct a thorough analysis of its performance in relation to the individual intervention cases.

**Format of Inputs:** To support your analysis, you must insert figures in the designated sections. These visualizations are critical for substantiating your claims. The following graphs can be included:

- **Contour Plots:** These can show spatial distributions of environmental conditions (e.g., air temperature,  $T_{air}$ ) or thermal comfort indices (e.g., Physiological Equivalent Temperature, PET) at specific times, such as **daytime** (e.g., at 12:00 or 16:00) versus **nighttime** (e.g., at 00:00 or 04:00).
- **Difference Plots:** Contour plots illustrating the **absolute difference** (e.g.,  $\Delta T_{air}$ ) between your chosen mitigation scenario and the baseline are highly encouraged to precisely quantify the impact.
- **Time-Series Plots:** These plots show the evolution of one or more variables (y-axis) over the full 24-hour simulation period (x-axis). You can plot multiple lines on a single graph to directly compare the diurnal performance of your mitigation scenario against the baseline.

When you combine multiple plots into a single composite figure, you must label each panel (A, B, C, etc.), provide a detailed caption that explains the content of each panel (e.g., "*Figure 1.1: (A) Contour plot of air temperature at 0.2 m above ground level at 14:00; (B) Absolute difference in  $T_{air}$  compared to baseline...*"), and refer to these specific panels in your written analysis (e.g., "*As shown in Figure 1.1(A)...*").

Please keep your written responses and figures within the designated answer boxes. The space provided is meant to guide the length of your answers, so focus on including only essential and factual information rather than lengthy descriptions.

**Evaluation:** The report will be evaluated based on the completeness and accuracy of the answers to each question, as well as the correct use of terminology and the clarity of the explanations of the phenomena. Individual grades will reflect both the quality of each student's work on their assigned tasks and their contribution to the group's Task 5. The report is worth a total of **50 points**: a maximum of **30 points** will be awarded for the quality of individual work and **20 points** for the group work.

### Submission Instructions:

1. Name your final file as follows: **Group Number\_CIVIL309\_Project II.pdf**
2. Submit your final file on Moodle, **deadline - December 19 at 16:00**

**Group Information:** Please enter your group information in the table below. The proposed distribution of analysis tasks among group members is as follows:

- **Student A:** Building–environment analysis *For odd-numbered groups (e.g., groups 1, 3, etc.), Student A should focus on urban forms (S1); for even-numbered groups (e.g., groups 2, 4, etc.), Student A should focus on building materials (S2).*
- **Student B:** Ground–environment analysis (S3)
- **Student C:** Vegetation–environment analysis (S4)
- **Student D:** Water–environment analysis (S5)
- **All members:** Combined effect analysis (S6)

#### Group Information

**Group Number:**

**Student A Name:**

**SCIPER:**

**Student B Name:**

**SCIPER:**

**Student C Name:**

**SCIPER:**

**Student D Name:**

**SCIPER:**

**Collaborative work on the report:** This project report is available on Moodle in two forms:

1. A single, complete PDF file containing all tasks (ideal for understanding the full project).
2. Separate PDF files, one for each individual task (Task 1, Task 2, etc.).

A recommended method for collaborative work is for each student to download and complete their assigned individual task PDF. After all individual tasks are finished, the group can merge these completed PDFs together (along with the final group task and introductory pages) into one file.

**Feedback:** After completing the report, please share your feedback about your experience by filling out this survey: <https://forms.gle/kETV2nCTRhN6j2A38>