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
Building-Environment Analysis (S1 - S2)	*Urban Form (S1) and Building Materials (S2)*	*urban form* - S1.1, S1.2, S1.3; *building materials* - S2.1, S2.2, S2.3
Ground-Environment Analysis (S3)	*Ground Modification*	S3.1, S3.2, S3.3
Vegetation-Environment Analysis (S4)	*Vegetation Strategies*	S4.1, S4.2, S4.3
Water-Environment Analysis (S5)	*Water Bodies*	S5.1, S5.2, S5.3
Combined Effects Analysis (S6)	*Integrated Mitigation Proposal*	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	**Baseline**	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
Group 1: Urban Form				
S1.1	Tall Canyon	Aligned grid of 4x4 buildings. Building height - 30 m, 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, street width - 30 m. 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	Staggered grid 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
Group 2: Building Materials				
S2.1	Painted Façades	Aligned grid of 4x4 buildings. Building height - 16 m, street width - 16 m. Building façade surface - white paint (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. Building façade material - glass (roof is concrete); asphalt ground. No vegetation.	Effect of shortwave and longwave radiation, heat storage, surface temperatures.	L3, L6

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Table 2 continued from previous page

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. Building façade - green walls (roof is concrete); asphalt ground. No vegetation on the ground.	Cooling from evapotranspiration (Q_E), surface temperatures, and longwave radiation.	L3, L4, L6, L9
Group 3: Ground Modification				
S3.1	Light Concrete	Aligned grid of 4x4 buildings. Building height - 16 m, street width - 16 m. Concrete buildings, ground - light concrete. No vegetation.	Effect of albedo on surface temperature, radiation balance (Q^*), and stored heat (ΔQ_S).	L3, L7
S3.2	Sandy Loam Ground	Aligned grid of 4x4 buildings. Building height - 16 m, street width - 16 m. Concrete buildings, ground - sandy loam soil. 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, ground - grass (h=25 cm).	Impact of a low, continuous vegetative cover on surface temperature and latent heat flux (Q_E).	L7, L9
Group 4: Vegetation Strategies				
S4.1	Hedges	Aligned grid of 4x4 buildings. Building height - 16 m, street width - 16 m. Concrete buildings, asphalt ground. Vegetation - hedges (h=1 m) along the streets.	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. Vegetation - deciduous trees (Betula species) along the streets.	Effect of shading and evapotranspiration from tree canopies on canyon climate.	L4, L9

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Table 2 continued from previous page

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. Vegetation - deciduous trees (Acer species) along the streets.	Effect of shading and evapotranspiration from tree canopies on canyon climate.	L4, L9
Group 5: Water Bodies				
S5.1	Mist Nozzles	Aligned grid of 4x4 buildings. Building height - 16 m, street width - 16 m. Concrete buildings, asphalt ground. No vegetation, water feature - an active misting/spray system at 3 m height along the buildings.	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, water feature - a water fountain (h=4 m) along the buildings.	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, water feature - water reservoirs at the ground level along the buildings.	Cooling from evaporation and the effect of water's high thermal inertia.	L4, L8
Group 6: Combination Scenarios				
S6.1	Holistic Nature Based Solutions	Combines S1.3 (Staggered) + S2.3 (Green Façades) + S3.3 (Grass) + S4.2 (Trees Betula) + S5.3 (Water Reservoir).	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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Table 2 continued from previous page

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° 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.

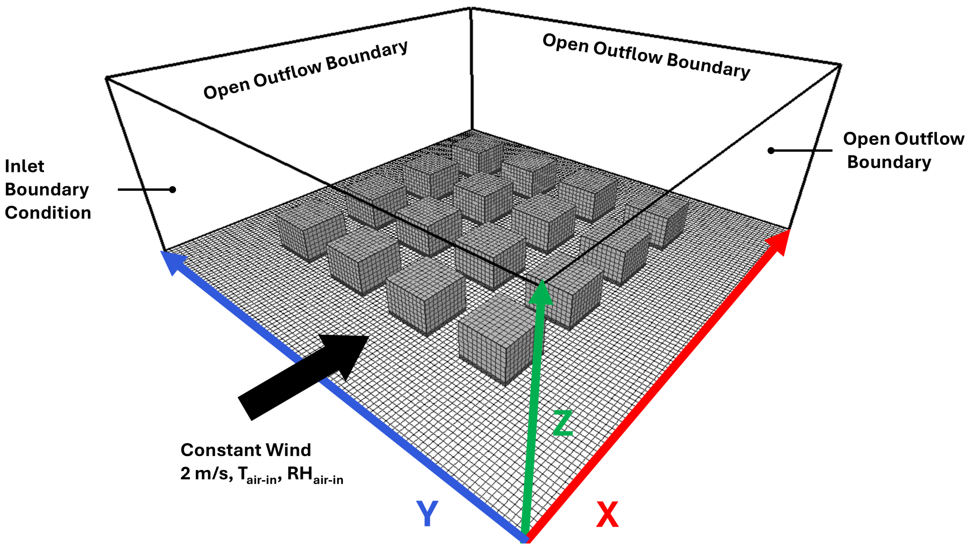

Figure 1: Illustration of the ENVI-met simulation domain, depicting the constant wind input from the North and the open outflow boundaries on the other sides. The text also indicates that temperature, humidity, and radiation are dynamically forced from external meteorological data.

C. Overview of weather conditions used in simulation scenarios

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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.

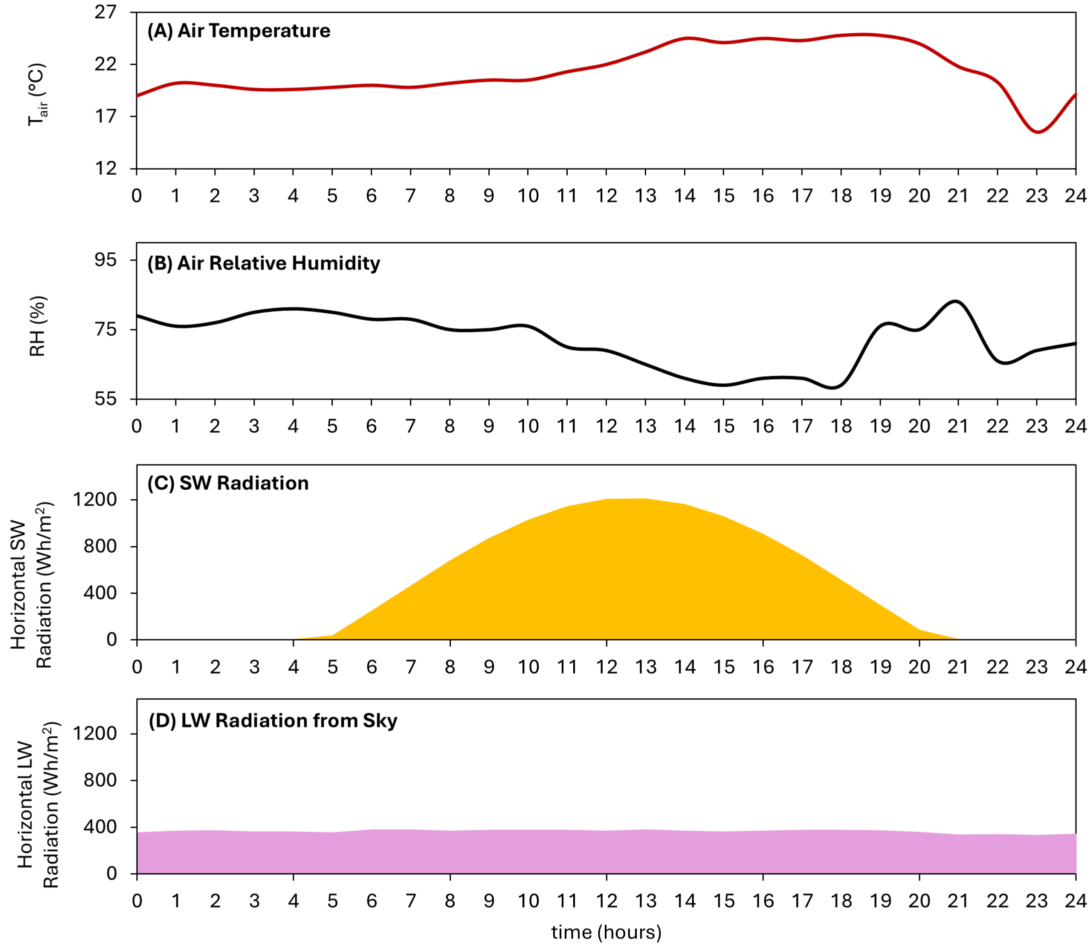

Figure 2: Overview of weather parameters: (A) Air temperature (°C), (B) Relative humidity (%), (C) Total shortwave solar radiation, horizontal (Wh/m^2), and (D) Longwave radiation from sky, horizontal (Wh/m^2).

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
S0 Asphalt (baseline)	0.12	0.90	0	Roughness length z_0=0.01 m
S3.1 Light Concrete	0.50	0.90	0	Roughness length z_0=0.01 m
S3.2 Sandy Loam	0.3	0.95	0	Roughness length z_0= 0.015 m
S3.3 Grass Cover	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
S0 Baseline (Outer Plaster)	0.60	0.40	0	0.93
S2.1 Painted Façade (White Paint)	0.20	0.80	0	0.93
S2.2 Glass Façade (Single-Pane Clear)	0.05	0.05	0.9	0.9
S2.3 Green Façade (Plant foliage)	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
Greening Coverage	0.3 m
Substrate Layer	10 cm sandy loam (albedo 0.3, emissivity 0.95)
Insulation Layer	5 cm styrofoam
Air Gap	0.2 m between substrate and wall

Table 6: General Properties of Plants

Scenario / Plant Type	Height (m)	Diam. (m)	α	ϵ	τ	LAI	LAD
S2.3 Plant - *Funika*	0.3	n/a	0.20	0.97	0.30	1.5	0.15
S3.3 Grass - aver	0.25	n/a	0.20	0.97	0.30	2.0	0.3
S4.1 Hedges - dense	1.0	n/a	0.20	0.97	0.30	1.0	1.0
S4.2 Tree - *Betula*	6.0	7.0	0.18	0.96	0.30	4.0	0.8
S4.3 Tree - *Acer*	11.0	9.0	0.50	0.96	0.30	5.0	0.7

* α (Albedo), ϵ (Emissivity), τ (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)	ρ (kg/m^3)	C_{vol} (MJ/m^3·K)
Building Surfaces					
Wall Construction (S0, etc.)	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
Glass Construction (S2.2)	Glass (single pane)	1.05	750	2500	1.88
Ground Surfaces					
Asphalt (S0)	Asphalt (30 cm)	0.90	969	2322	2.25
	Sandy Loam (30-200 cm)	0.50	880	1500	1.32
Sandy Loam (S3.2)	Sandy Loam (200 cm)	0.50	880	1500	1.32
Light Concrete (S3.1)	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 ρ.

Table 8: Detailed Biomechanical Properties of Tree Species

Scenario / Tree Species	Leaf Weight [g/m^2]	Root Diameter [m]	Root Depth [m]	Wood Density [kg/m^3]
S4.2 Tree - *Betula Pendula*	100.0	10.0	1.40	590.0
S4.3 Tree - *Acer Negundo*	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)
S5.1 Misting System	Active spray	3.0	Down	5.0 (constant 24h)
S5.2 Water Fountain	Active spray	$0 \rightarrow 4.0$	Up	5.0 (constant 24h)
S5.3 Water Reservoir	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=0.01m, ϵ=0.9). Ground balance does not account for direct solar exchange; temperature development may be underestimated.

================ REPORT INSTRUCTIONS ================

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., ΔT_{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`

Task 1: Building-Environment Analysis (Student A)

Scenario Selection and Justification *Based on your group number (see "Group Information" page), select the most effective scenario from your assigned category (Group S1 for odd-numbered groups, Group S2 for even-numbered groups). State your choice below and provide a detailed justification based on theoretical principles.*

Selected Scenario:

Justification:

A. Analysis of Environmental Conditions (T_{air}, MRT, RH, V_{air})

Insert supporting figures (e.g., contour or time-series plots) below. You may insert a composite figure with multiple panels (up to 6); if so, please label them (a), (b), etc., and describe each panel in your caption. Refer to all figures in your analysis (e.g., "As shown in Figure 1.1(A)...").

Insert figure(s) for Environmental Conditions analysis
(Use a PDF editor to insert your image(s) here)

Figure 1.1:

*Provide a comprehensive analysis of the changes in environmental conditions. Compare the mitigation scenario to the baseline (S0) for both **daytime** and **nighttime**. Explain the physical mechanisms driving these changes (e.g., how building height affects shading and reduces MRT, or how green facades increase RH through evapotranspiration).*

B. Analysis of Surface Fluxes

Insert supporting figures, provide captions, and refer to them in your analysis.

Insert figure(s) for Surface Flux analysis
(Use a PDF editor to insert your image(s) here)

Figure 1.2:

Analyze how your chosen mitigation strategy alters the surface energy balance of the urban canyon. Focus on the key fluxes that are modified (e.g., for a green façade, discuss the increase in Q_E *and decrease in* Q_H*; for a tall canyon, discuss changes in the radiation budget and stored heat* ΔQ_S*). Compare the magnitude and diurnal pattern of these fluxes to the baseline scenario.*

C. Analysis of Thermal Comfort (PET)

Insert supporting figures, provide captions, and refer to them in your analysis.

Insert figure(s) for Thermal Comfort analysis
(Use a PDF editor to insert your image(s) here)

Figure 1.3:

Analyze the impact on human thermal comfort by comparing the Physiological Equivalent Temperature (PET) between the scenarios. Discuss where and when the greatest improvements in comfort are achieved. ***Importantly, link the calculated PET values to the corresponding thermal sensation and/or heat stress levels (e.g., "heat stress was reduced from 'Extreme Heat Stress' to 'Strong Heat Stress'" or thermal sensation was shifted from 'warm' to 'slightly warm').*** *Relate the changes in PET to the underlying changes in T_{air}, MRT, RH, and V_{air} you analyzed in Part A.*

Task 2: Ground-Environment Analysis (Student B)

Scenario Selection and Justification *From the scenarios in Group 3 (S3.1 to S3.3), select the one you hypothesize to be the most effective for mitigating urban heat compared to the baseline scenario S0. State your choice below and provide a detailed justification.*

Selected Scenario:

Justification:

A. Analysis of Environmental Conditions (T_{air}, MRT, RH, V_{air})

Insert supporting figures (e.g., contour or time-series plots) below. You may insert a composite figure with multiple panels; if so, please label them (a), (b), etc., and describe each panel in your caption. Refer to all figures in your analysis.

Insert figure(s) for Environmental Conditions analysis
(Use a PDF editor to insert your image(s) here)

Figure 2.1:

*Provide a comprehensive analysis of the changes in environmental conditions for both **daytime** and **nighttime**. Explain the physical mechanisms (e.g., how high albedo pavement reduces surface temperature and subsequently T_{air} and MRT, or how sandy loam increases RH).*

B. Analysis of Surface Fluxes

Insert supporting figures, provide captions, and refer to them in your analysis.

Insert figure(s) for Surface Flux analysis
(Use a PDF editor to insert your image(s) here)

Figure 2.2:

Analyze how the modified ground cover alters the surface energy balance. For light concrete, focus on the reduction in net shortwave radiation and subsequent changes in Q_H *and* ΔQ_S*. For sandy loam or grass, discuss the introduction of* Q_E *and its effect on the partitioning of available energy compared to the impervious baseline.*

C. Analysis of Thermal Comfort (PET)

Insert supporting figures, provide captions, and refer to them in your analysis.

Insert figure(s) for Thermal Comfort analysis
(Use a PDF editor to insert your image(s) here)

Figure 2.3:

Analyze the impact on PET. Discuss where and when the greatest improvements in comfort are achieved. Relate the changes in PET to the underlying changes in the environmental variables from Part A.

Task 3: Vegetation-Environment Analysis (Student C)

Scenario Selection and Justification *From the scenarios in Group 4 (S4.1 to S4.3), select the one you hypothesize to be the most effective for mitigating urban heat compared to the baseline scenario S0. State your choice below and provide a detailed justification.*

Selected Scenario:

Justification:

A. Analysis of Environmental Conditions (T_{air}, MRT, RH, V_{air})

Insert supporting figures (e.g., contour or time-series plots) below. You may insert a composite figure with multiple panels; if so, please label them (a), (b), etc., and describe each panel in your caption. Refer to all figures in your analysis.

Insert figure(s) for Environmental Conditions analysis
(Use a PDF editor to insert your image(s) here)

Figure 3.1:

*Provide a comprehensive analysis of the changes in environmental conditions for both **daytime** and **nighttime**. Explain how the chosen vegetation (hedges or trees) influences each variable through mechanisms like shading, evapotranspiration, and modification of airflow (V_{air}).*

B. Analysis of Surface Fluxes

Insert supporting figures, provide captions, and refer to them in your analysis.

Insert figure(s) for Surface Flux analysis
(Use a PDF editor to insert your image(s) here)

Figure 3.2:

Analyze the significant alteration of the surface energy balance caused by vegetation. Discuss the magnitude of the latent heat flux (Q_E) and explain its diurnal cycle. How does the presence of vegetation reduce the sensible heat flux (Q_H) and ground heat flux (ΔQ_S) compared to the asphalt baseline?

C. Analysis of Thermal Comfort (PET)

Insert supporting figures, provide captions, and refer to them in your analysis.

Insert figure(s) for Thermal Comfort analysis
(Use a PDF editor to insert your image(s) here)

Figure 3.3:

Analyze the impact on PET. Vegetation is often highly effective at improving comfort. Explain the relative contributions of shading (reducing MRT) and evaporative cooling (reducing T_{air} and increasing RH) to the overall improvement in PET. **Importantly, link the calculated PET values to the corresponding thermal sensation and/or heat stress levels (e.g., "heat stress was reduced from 'Extreme Heat Stress' to 'Strong Heat Stress'" or thermal sensation was shifted from 'warm' to 'slightly warm').**

Task 4: Water-Environment Analysis (Student D)

Scenario Selection and Justification *From the scenarios in Group 5 (S5.1 to S5.3), select the one you hypothesize to be the most effective for mitigating urban heat compared to the baseline scenario S0. State your choice below and provide a detailed justification.*

Selected Scenario:

Justification:

A. Analysis of Environmental Conditions (T_{air}, MRT, RH, V_{air})

Insert supporting figures (e.g., contour or time-series plots) below. You may insert a composite figure with multiple panels; if so, please label them (a), (b), etc., and describe each panel in your caption. Refer to all figures in your analysis.

Insert figure(s) for Environmental Conditions analysis

(Use a PDF editor to insert your image(s) here)

Figure 4.1:

Provide a comprehensive analysis of the changes in environmental conditions for both ***daytime*** *and* ***nighttime****. Explain the primary cooling mechanism (evaporation) and its impact on* T_{air} *and RH. For the reservoir, also discuss the role of high thermal inertia on the diurnal temperature profile.*

B. Analysis of Surface Fluxes

Insert supporting figures, provide captions, and refer to them in your analysis.

Insert figure(s) for Surface Flux analysis
(Use a PDF editor to insert your image(s) here)

Figure 4.2:

Analyze how the water feature acts as a major source of latent heat flux (Q_E). Compare the magnitude of this flux to the sensible heat flux (Q_H). For the reservoir, discuss how its large heat storage capacity affects the ground heat flux (ΔQ_S) and the release of heat at night.

C. Analysis of Thermal Comfort (PET)

Insert supporting figures, provide captions, and refer to them in your analysis.

Insert figure(s) for Thermal Comfort analysis
(Use a PDF editor to insert your image(s) here)

Figure 4.3:

Analyze the impact on PET. Is the cooling effect localized or widespread? Discuss the trade-off between lower air temperature and potentially higher humidity on thermal sensation. **Importantly, link the calculated PET values to the corresponding thermal sensation and/or heat stress levels (e.g., "heat stress was reduced from 'Extreme Heat Stress' to 'Strong Heat Stress'" or thermal sensation was shifted from 'warm' to 'slightly warm').**

Task 5: Combined Effects Analysis (Group Work)

Scenario Selection and Justification *As a group, select one of the combined mitigation scenarios from Group 6 (S6.1 to S6.6). Analyze its performance relative to the baseline (S0) and, more importantly, relative to the individual component scenarios (e.g., how does S6.1 compare to just S1.3 or S2.3 alone?). You should include* ***2 individual scenarios*** *(total 3: Baseline + 2 individual). State your choice below and provide a justification for your selection.*

Selected Scenario:

Justification:

A. Analysis of Environmental Conditions (T_{air}, MRT, RH, V_{air})

Insert supporting figures (e.g., contour or time-series plots) below. Compare your S6 scenario to the baseline (S0) and to its key individual components (2).

Insert figure(s) for Environmental Conditions analysis
(Use a PDF editor to insert your image(s) here)

Figure 5.1:

Provide a comprehensive analysis of the changes in environmental conditions. Quantify the cooling/moistening effect and compare it to S0. Discuss how the combination of strategies (e.g., trees + cool pavement) provides a different result than each strategy alone.

B. Analysis of Surface Fluxes

Insert supporting figures, provide captions, and refer to them in your analysis. Focus on the combined effect on Q_E, Q_H, and ΔQ_S.

Insert figure(s) for Surface Flux analysis

(Use a PDF editor to insert your image(s) here)

Figure 5.2:

Analyze how the integrated strategy fundamentally alters the energy balance of the urban canyon. Discuss the shifts in the partitioning of energy (e.g., decrease in Q_H and ΔQ_S, increase in Q_E) and compare the magnitude of these changes to the individual scenarios.

C. Analysis of Thermal Comfort (PET)

Insert supporting figures, provide captions, and refer to them in your analysis. Use difference plots (S6 vs S0) to highlight the total improvement.

Insert figure(s) for Thermal Comfort analysis
(Use a PDF editor to insert your image(s) here)

Figure 5.3:

Analyze the combined impact on PET. Discuss where and when the greatest improvements in comfort are achieved. Is the combined effect greater than the sum of its parts? (i.e., is it synergistic?) **Importantly, link the calculated PET values to the corresponding thermal sensation and/or heat stress levels (e.g., "heat stress was reduced from 'Extreme Heat Stress' to 'Strong Heat Stress'" or thermal sensation was shifted from 'warm' to 'slightly warm').**

D. Reflection on Synergies and Limitations

Provide a final summary of your findings. Conclude on the effectiveness of your chosen integrated design versus isolated interventions. Reflect on any observed synergistic effects (where the combined effect is greater than the sum of individual effects) or antagonistic effects (where one strategy cancels out another). Finally, discuss the limitations of this idealized simulation.

— End of Project II —