Northumbria University NEWCASTLE

ANALYSING THE EFFECT OF BUILDING FAÇADE MATERIAL ON URBAN MICROCLIMATE UNDER UK WEATHER CONDITIONS

SHASHWAT S, KISHOR ZINGRE, and NIRAJ THURAIRAJAH

Faculty of Engineering and Environment, Northumbria University, Newcastle upon Tyne, United Kingdom NE1 8ST

Presented by - Shashwat

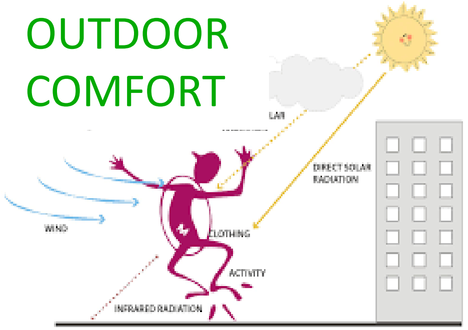
PhD candidate
Northumbria University
s.shashwat@northumbria.ac.uk
5th April 2022

Background

45% of CO_2 emission happens due to the building sector in the UK *(Duran, et al. 2021)*

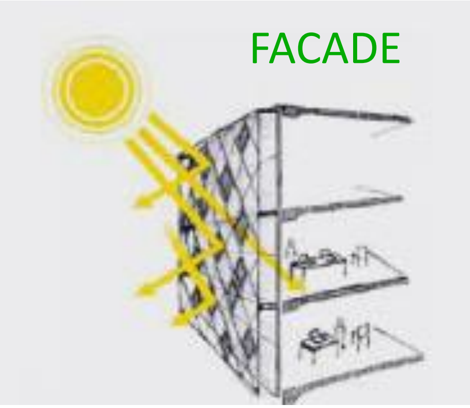
Higher urban air temperature compared to adjacent rural temperature 3° to 5° C *(Arshad, et al. 2021)*

Adverse Outdoor thermal comfort even in cities like London *(Salvati, et al. 2021) and* degraded air quality *(Liu et al. 2021)*



Building facade is very important in reducing CO_2 emission and improving thermal comfort. *(Bienvenido-Huertas, et al. 2018)*

Facade is a critical element that impacts both indoor and micro-climate condition *(Vallati, et al. 2015)*

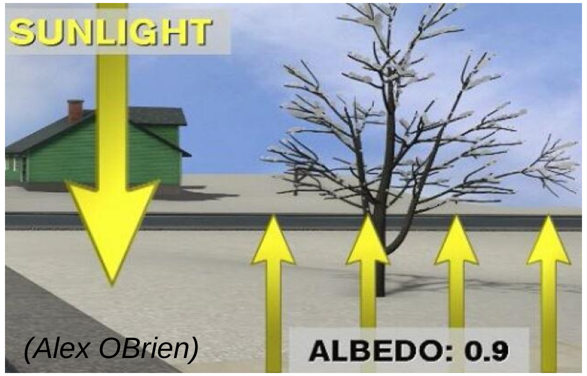


The purpose of this research is to analyse the impact of façade materials on urban microclimate.

Literature Review

10% of vegetation cover can reduce the temperature by 0.6°C *(Theeuwes, et al. 2012)*

High Albedo materials on a massive scale can lower the temperature by 2°C *(Taha, 1997)*



Porous concrete pavement can reduce a maximum of 6.6 °C as compared to regular concrete pavement. *(Cheng et al, 2019)*

A combination of High Albedo materials and vegetation with rooftop greenery can aid in reducing the temperature up to 4.2°C
(Sadoudi, 2014)

Research questions ?

What is the impact of building material on the microclimate under the UK's seasonal climatic conditions?

- What is the impact of thermophysical and surface radiation properties?

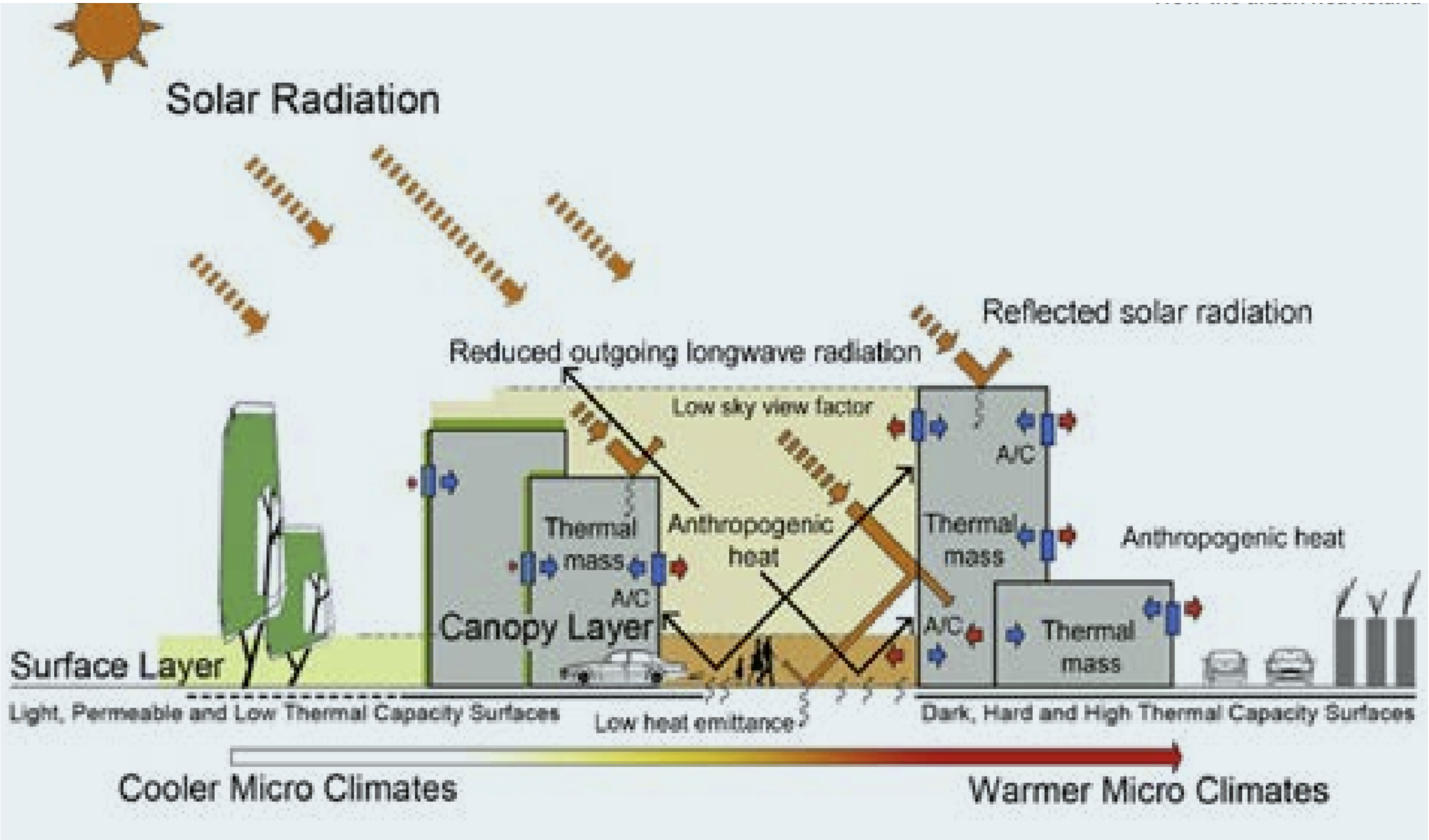
- Which façade material is most suited for optimisation of outdoor air temperature during
  - Summer season
  - Winter season

What is a microclimate ?

A local atmospheric zone where the climate differs from the surrounding area is known as an urban microclimate *(Bherwani et al, 2020).*

Factors impacting Microclimate-

- **Building facade**,
- Water bodies,
- Vegetation,
- Urban Fabric,
- Soil Conditions,
- wind speed & direction
- Human activities



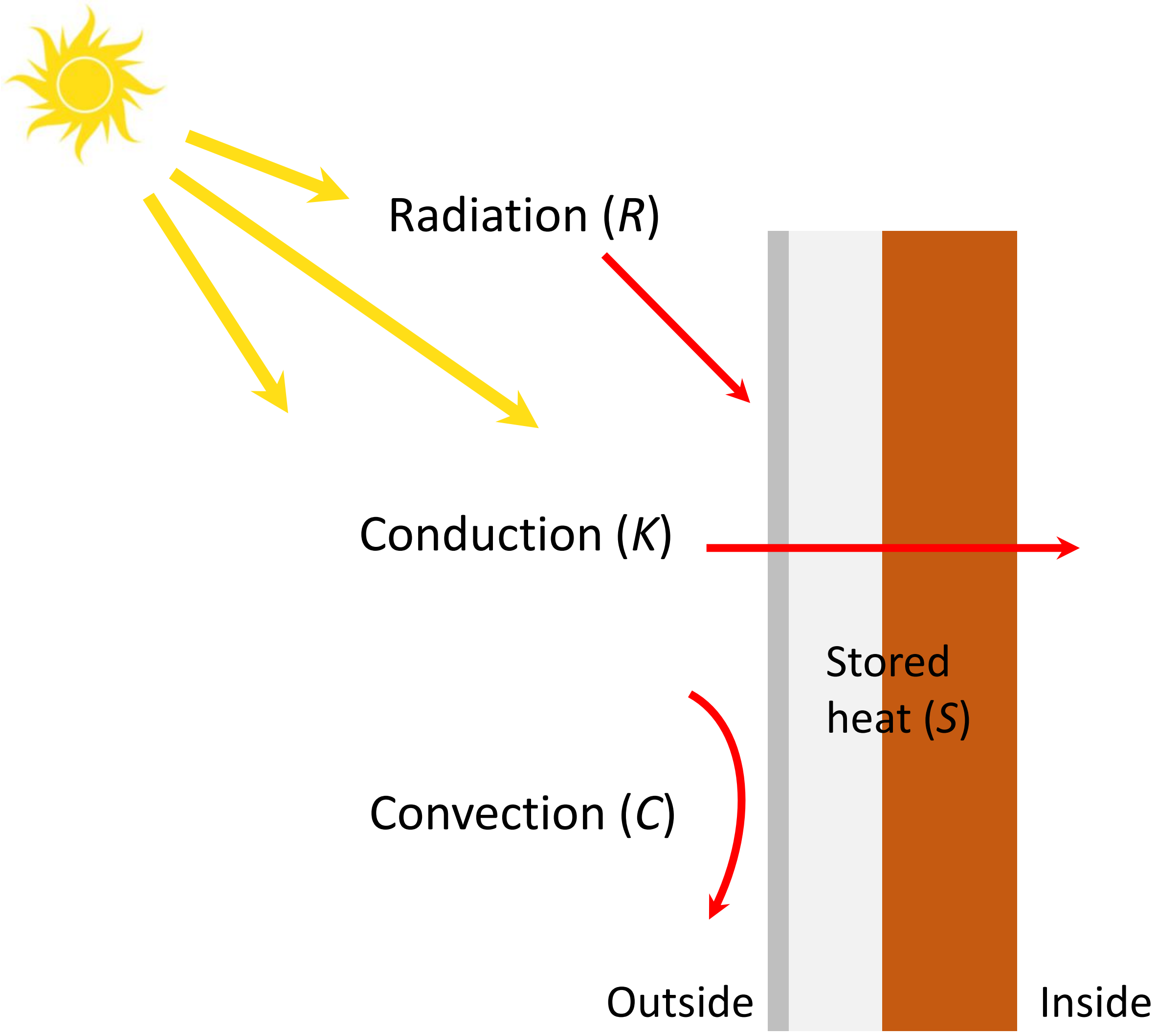
Microclimate Variation (Osmond, 2017)

Microclimate modelling

Heat Exchange calculation for façade during microclimatic simulation *(Huttner & Bruse, 2009)*:

$$R + C + K - S = 0$$

R	is the radiative heat exchange,
C	is the convective heat exchange,
K	is the conductive heat exchange,
S	is the stored heat.



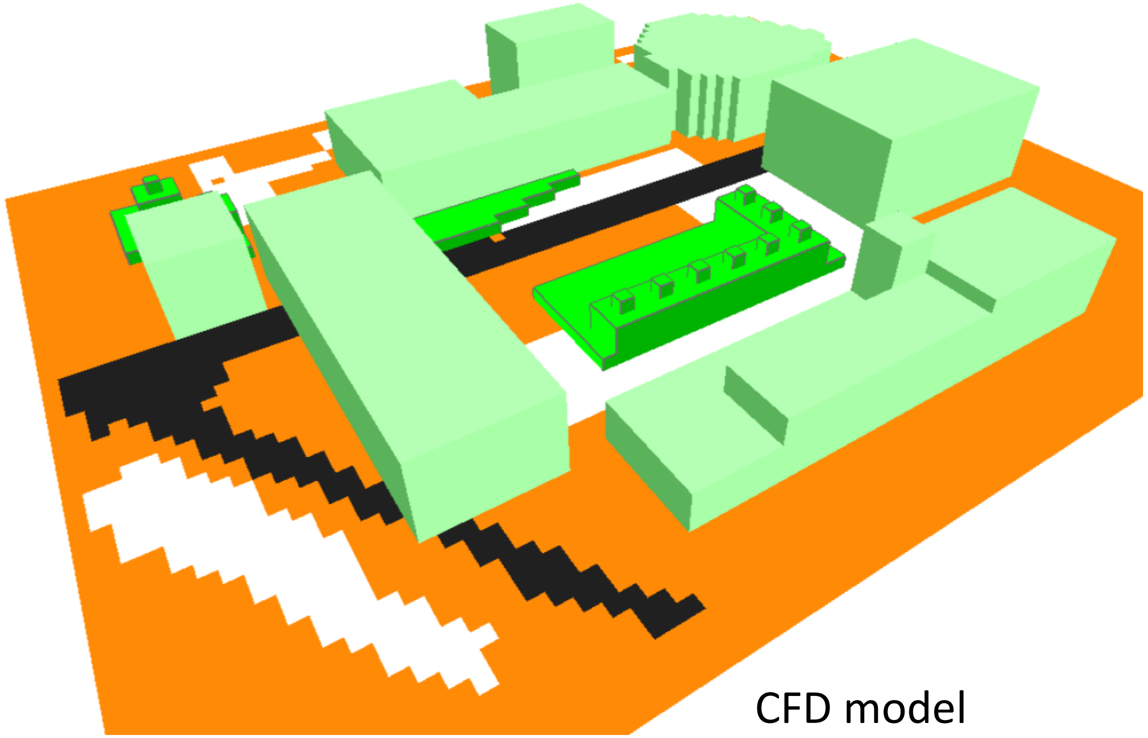
Methodology

❖ Applying CFD in the study of microclimate

- ❖ Analysis of flow field parameters – Air temperature, Wind direction & speed, pressure, and Relative Humidity

- ❖ Use of computing grid - Iterative approach, the differential equations are solved in each cell of the grid.

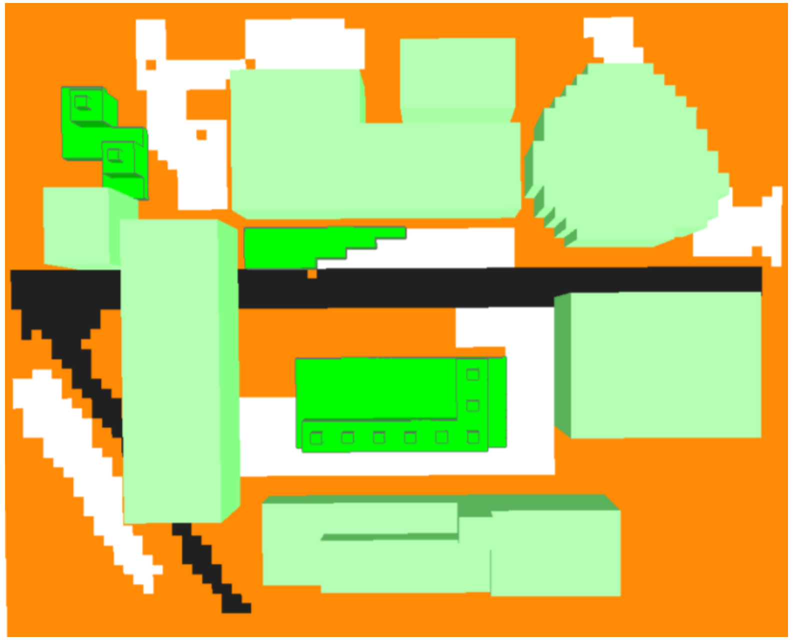
- ❖ Input data –
  - ❖ Initial condition – Meteorological parameters
  - ❖ Boundary conditions – Urban fabric morphological parameters



CFD model

Methodology

- **ENVI MET** Simulation Platform
  - Three-Dimensional Analysis
  - Holistic simulation approach – Modelling includes various critical elements interacting with each other –
    - Greenery,
    - building urban fabrics,
    - Road and pedestrian pathways,
    - water bodies.
  - Climatological data input –
    - Air Temperature
    - wind speed and direction
    - Relative humidity



Arial view of selected buildings (CFD model)

Computational Model

Academic buildings located on the campus of **Northumbria University, Newcastle Upon Tyne**

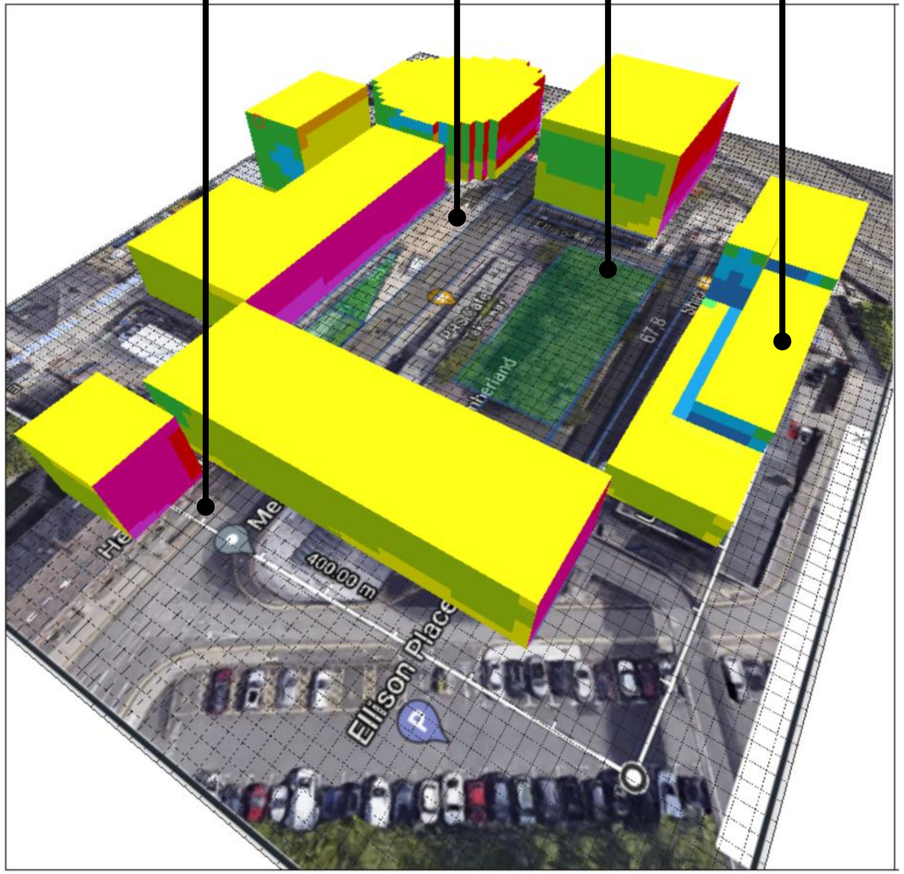
Digital image (Google earth)

Academic Buildings

Pedestrian Pathways

Greenery

Asphalt Road

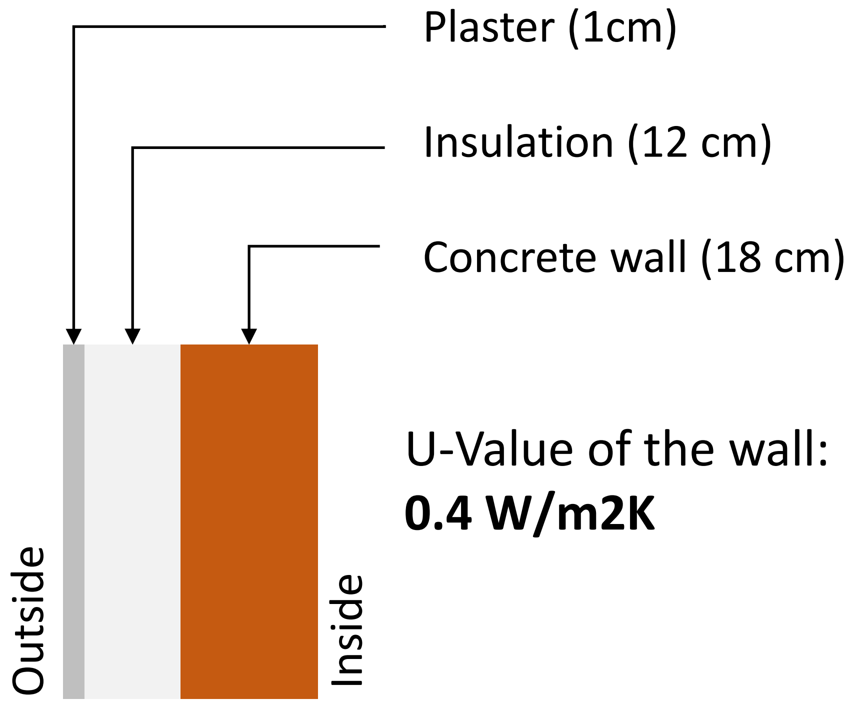


Computational model image

Simulation Input

- Simulation days
  - Representative Summer Day
  - Representative Winter Day

- Simulation start time – Midnight/8 AM
- Simulation duration – 24 hrs. (Summer), 8 hrs. (Winter)
- Grid Size – 2m X 2m

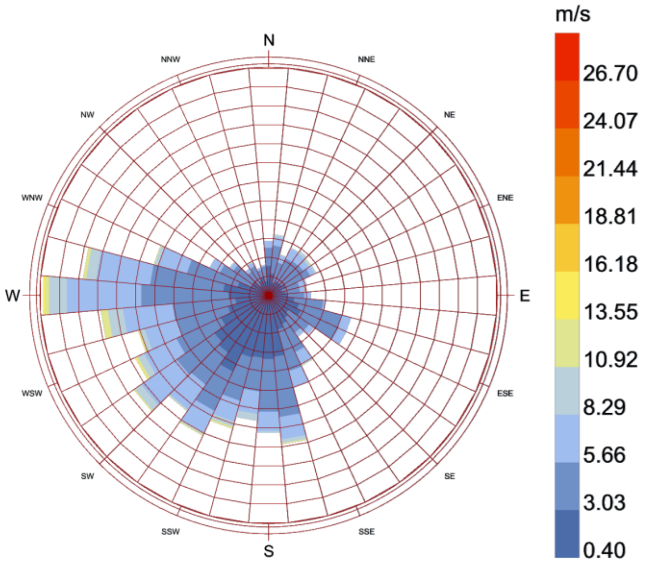


- Properties for different cases -

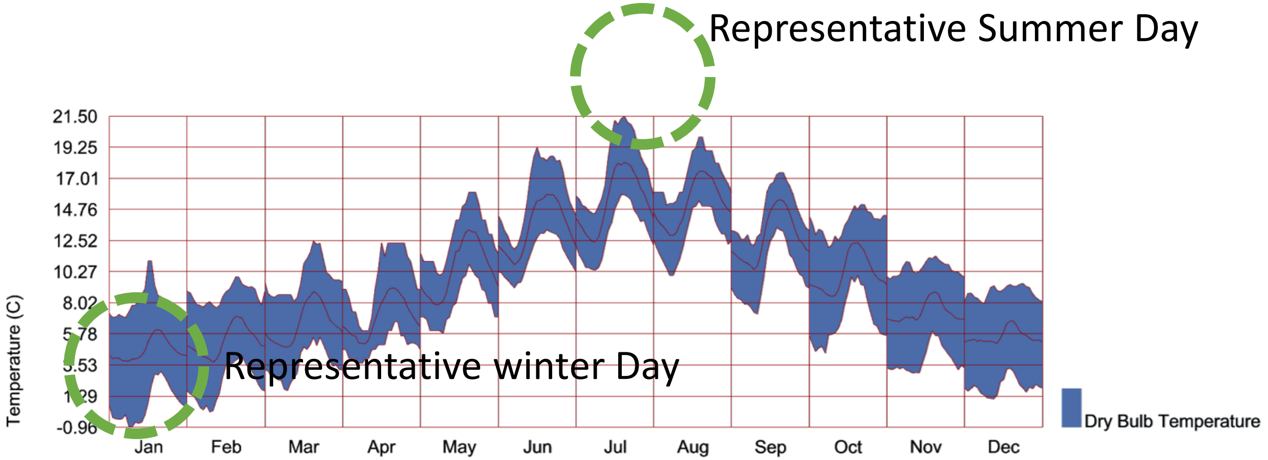
Cases	Reflectance	Emittance	Heat capacity (J/(Kg*K))
Baseline Case	0.1	0.9	850
High Reflectance	0.9	0.9	850
Low Emittance	0.1	0.1	850
PCM	0.1	0.9	4000

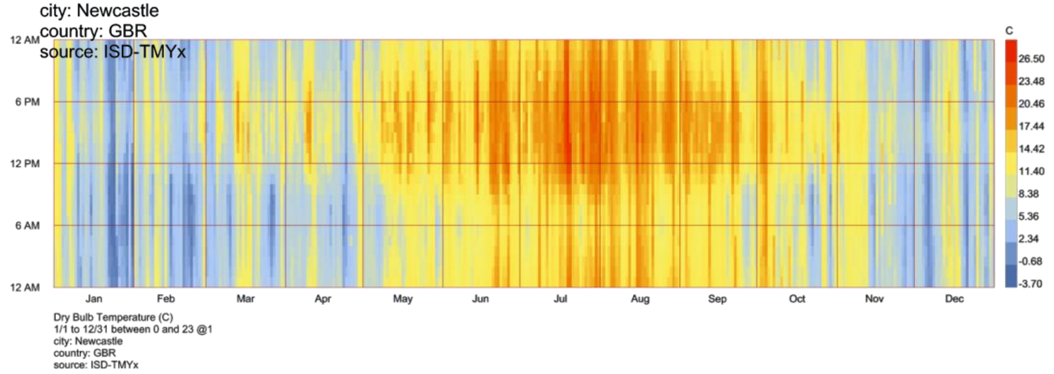
Weather Data

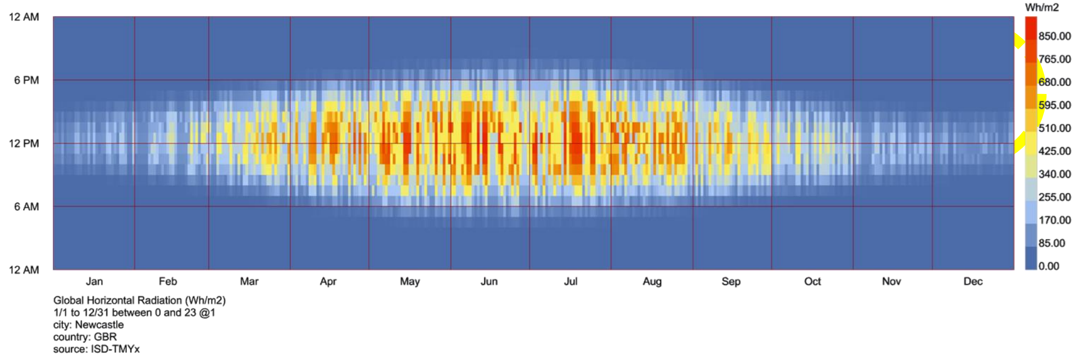
- **Weather data – Newcastle Upon Tyne**
  (https://www.ladybug.tools/epwmap/)
- **Simulation days**
  - Representative Summer Day -July
  - Representative Winter Day - Jan



Wind Speed (m/s)
city: Newcastle
country: GBR
source: ISD-TMYx
period: 1/1 to 12/31 between 0 and 23 @1
Calm for 2.83% of the time = 248 hours.
Each closed polyline shows frequency of 0.6% = 50 hours.





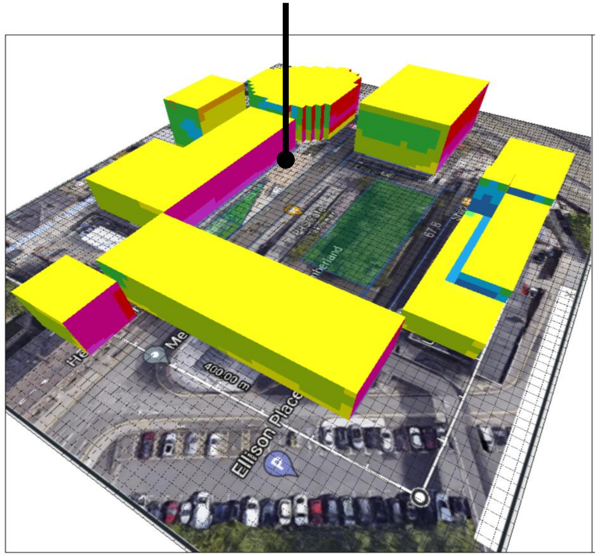


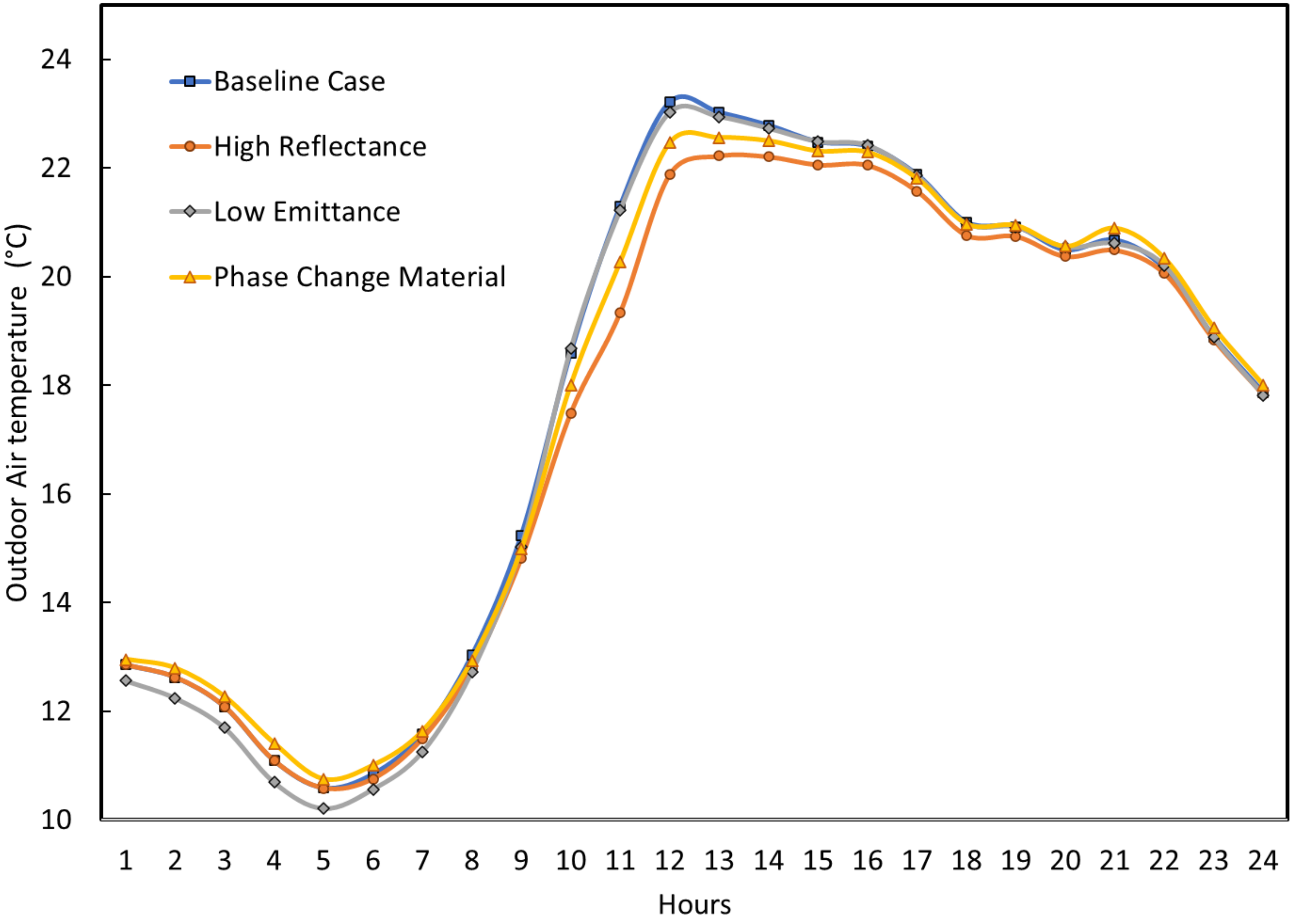
Result

Representative Summer Day

The focus is to find which building material is better for **reducing** the outdoor air temperature for enhancing outdoor thermal comfort for pedestrians.

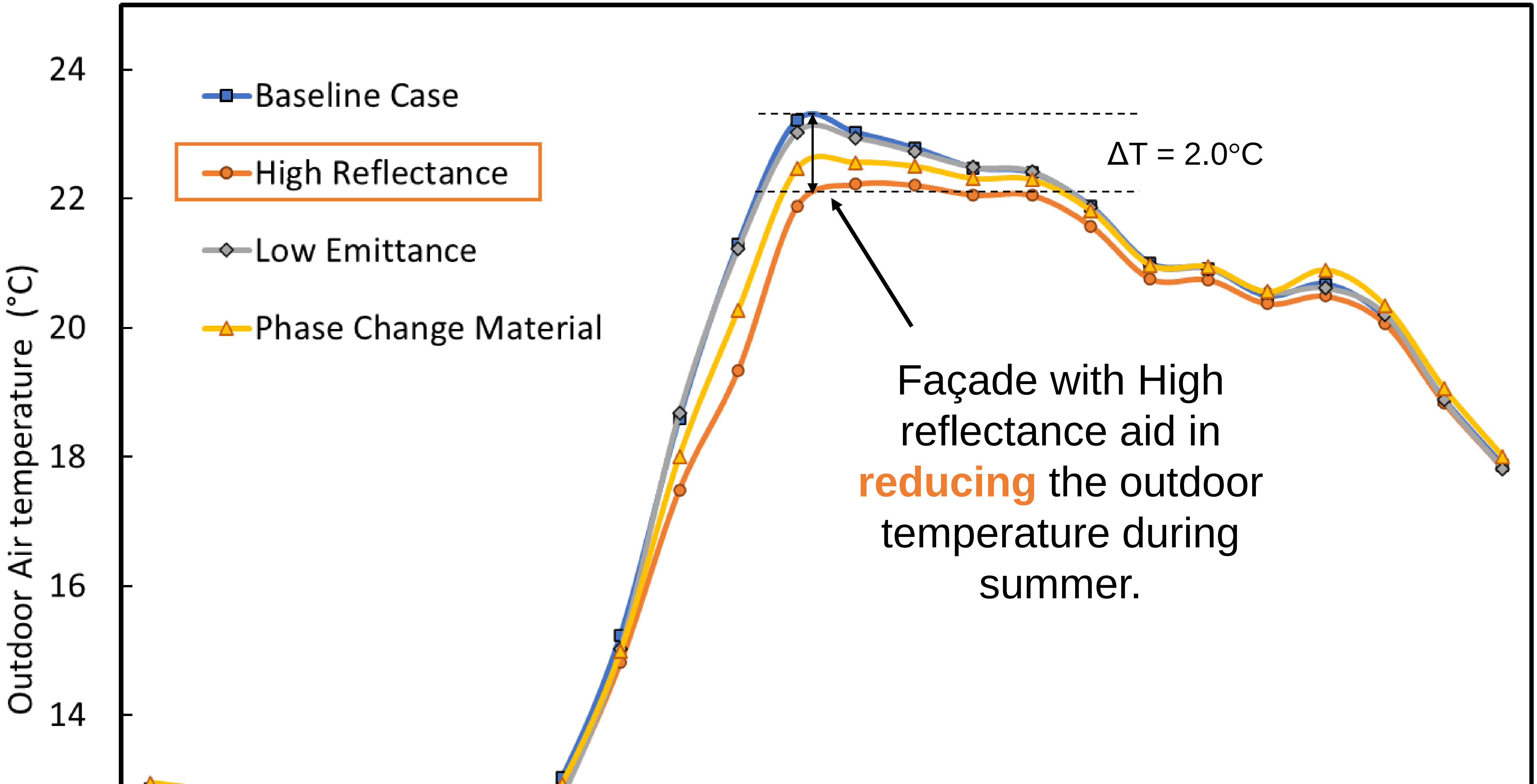
Pedestrian Pathways Grid



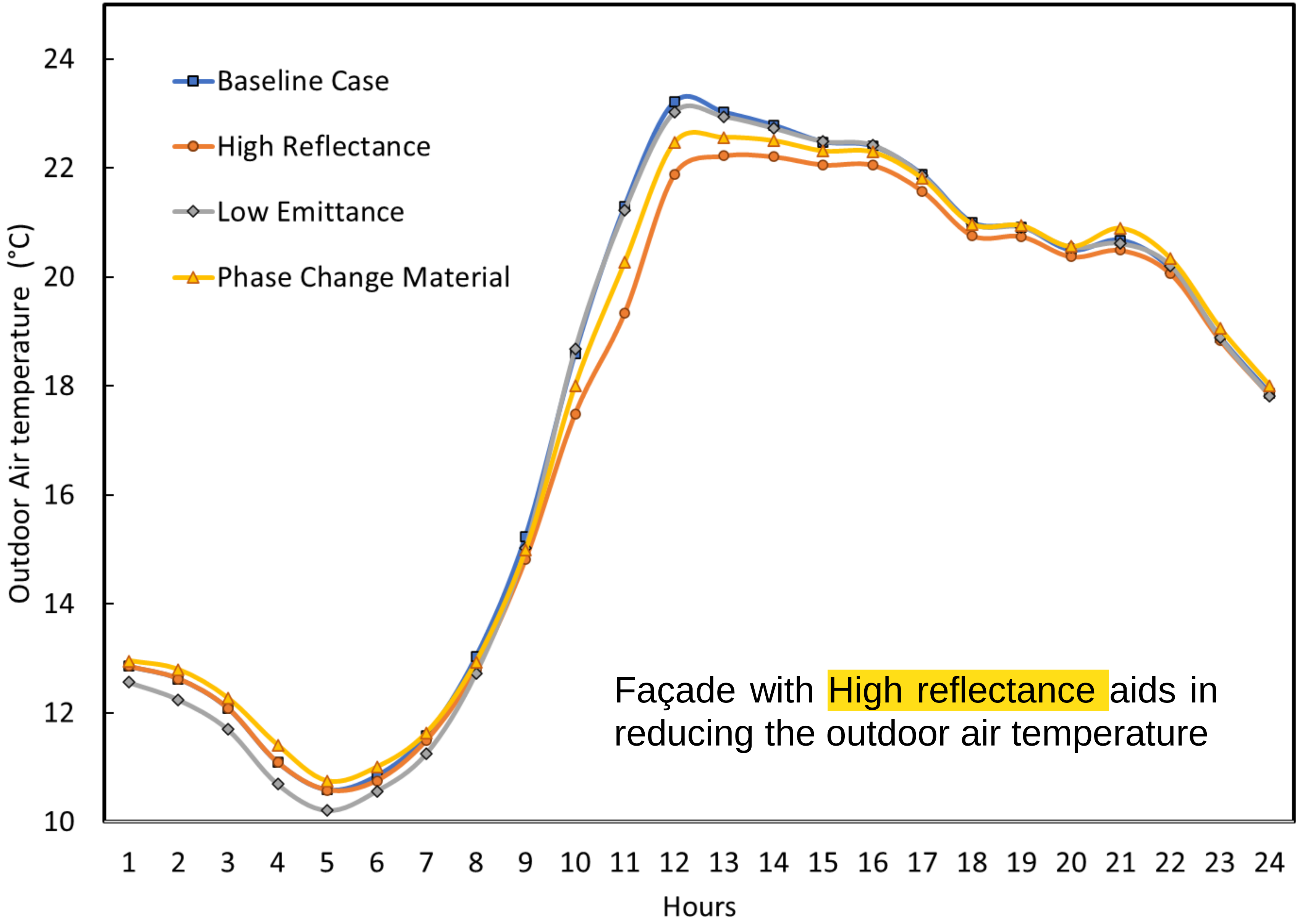


Cases	Reflectance	Emittance	Heat capacity (J/(Kg*K)
Baseline Case	0.1	0.9	850
High Reflectance	0.9	0.9	850
Low Emittance	0.1	0.1	850
PCM	0.1	0.9	4000

Representative Summer Day



Representative Summer Day

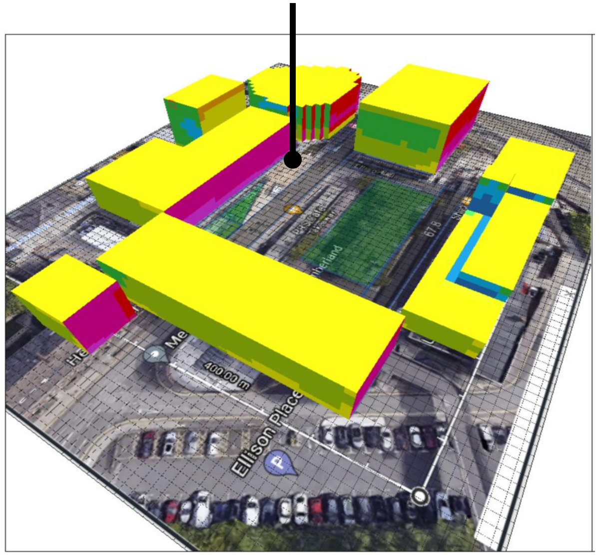


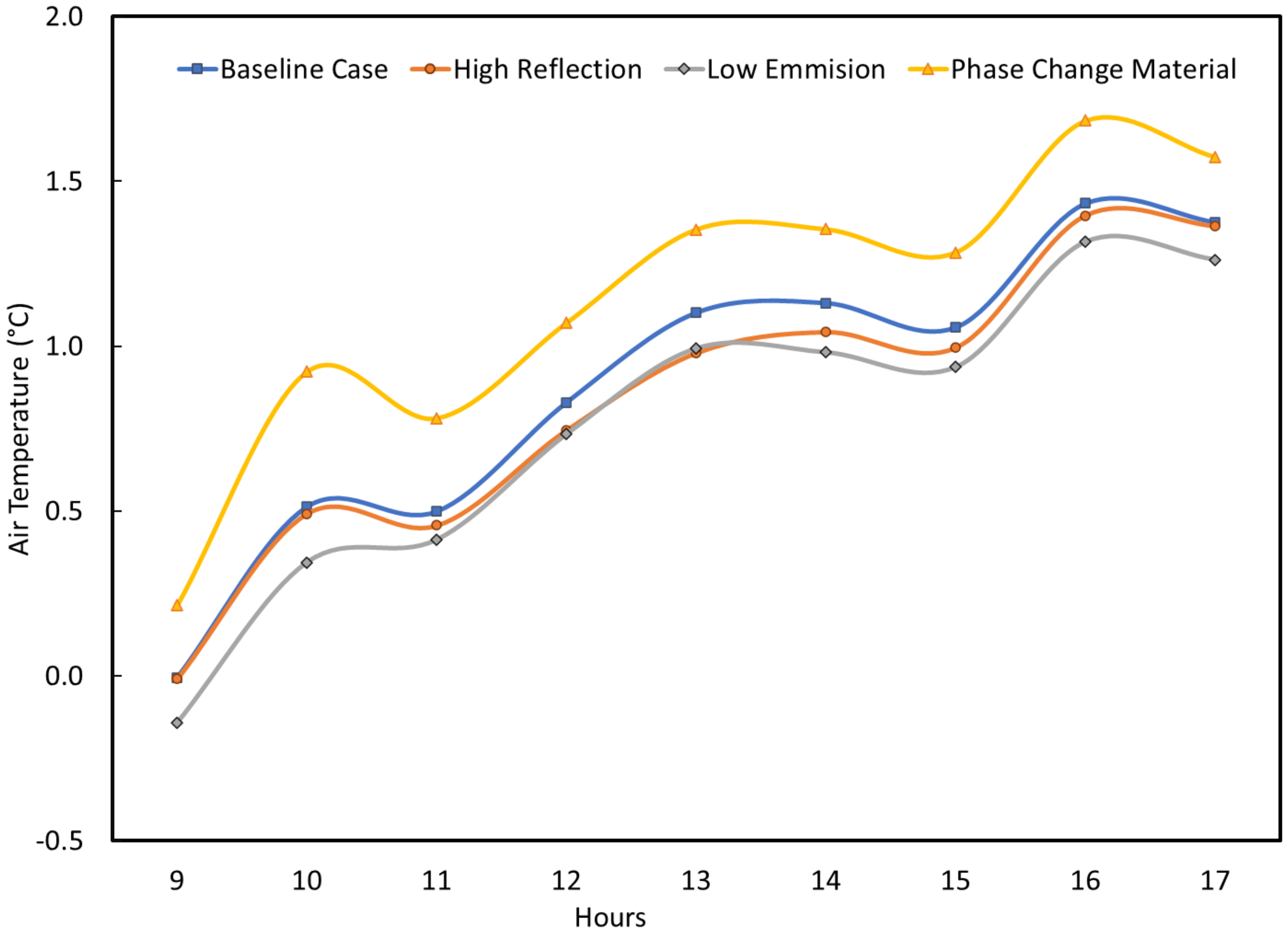
Result

Representative Winter Day

The focus is to find which building material is better for **increasing** the outdoor air temperature for enhancing outdoor thermal comfort.

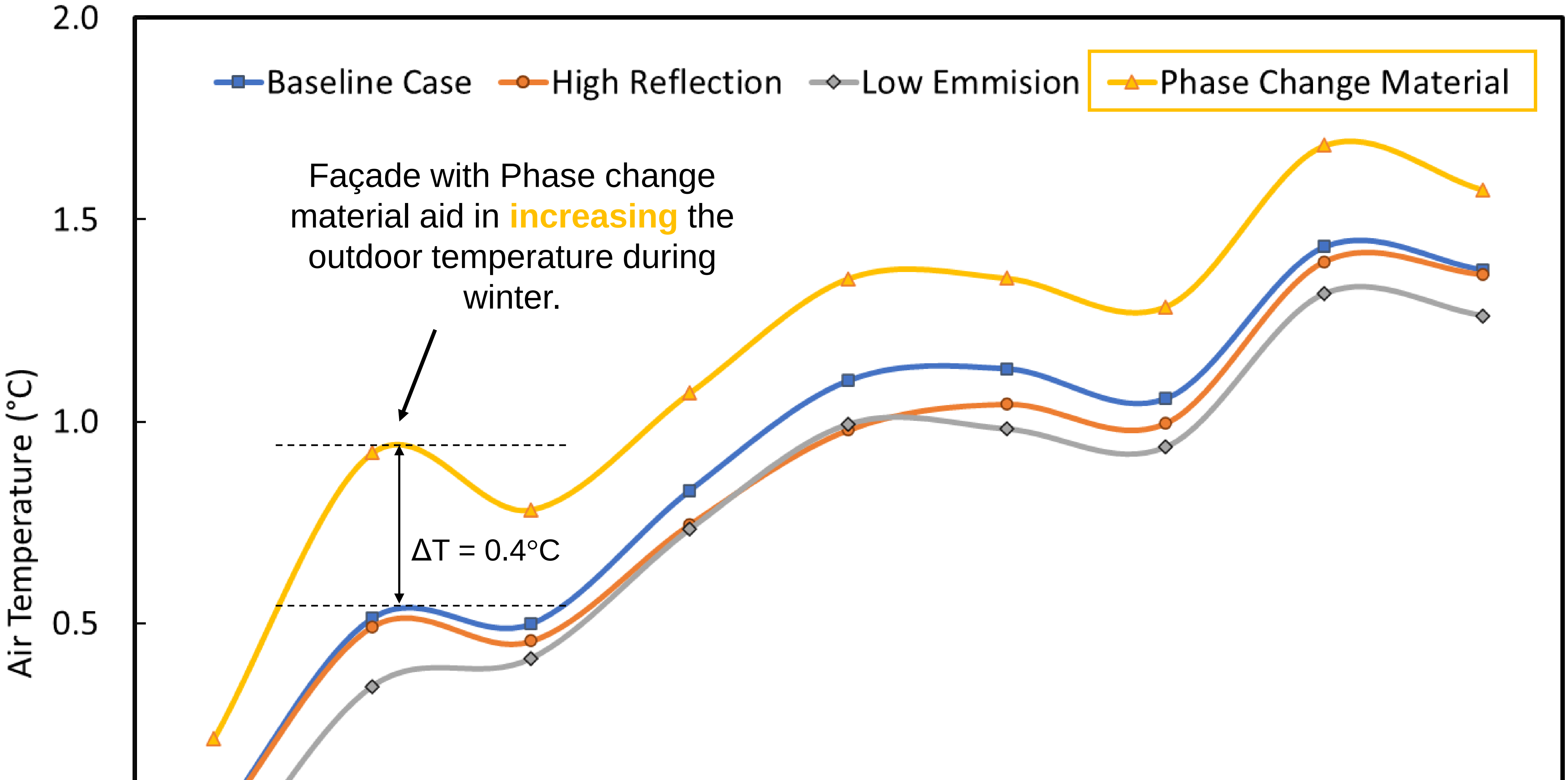
Pedestrian Pathways Grid



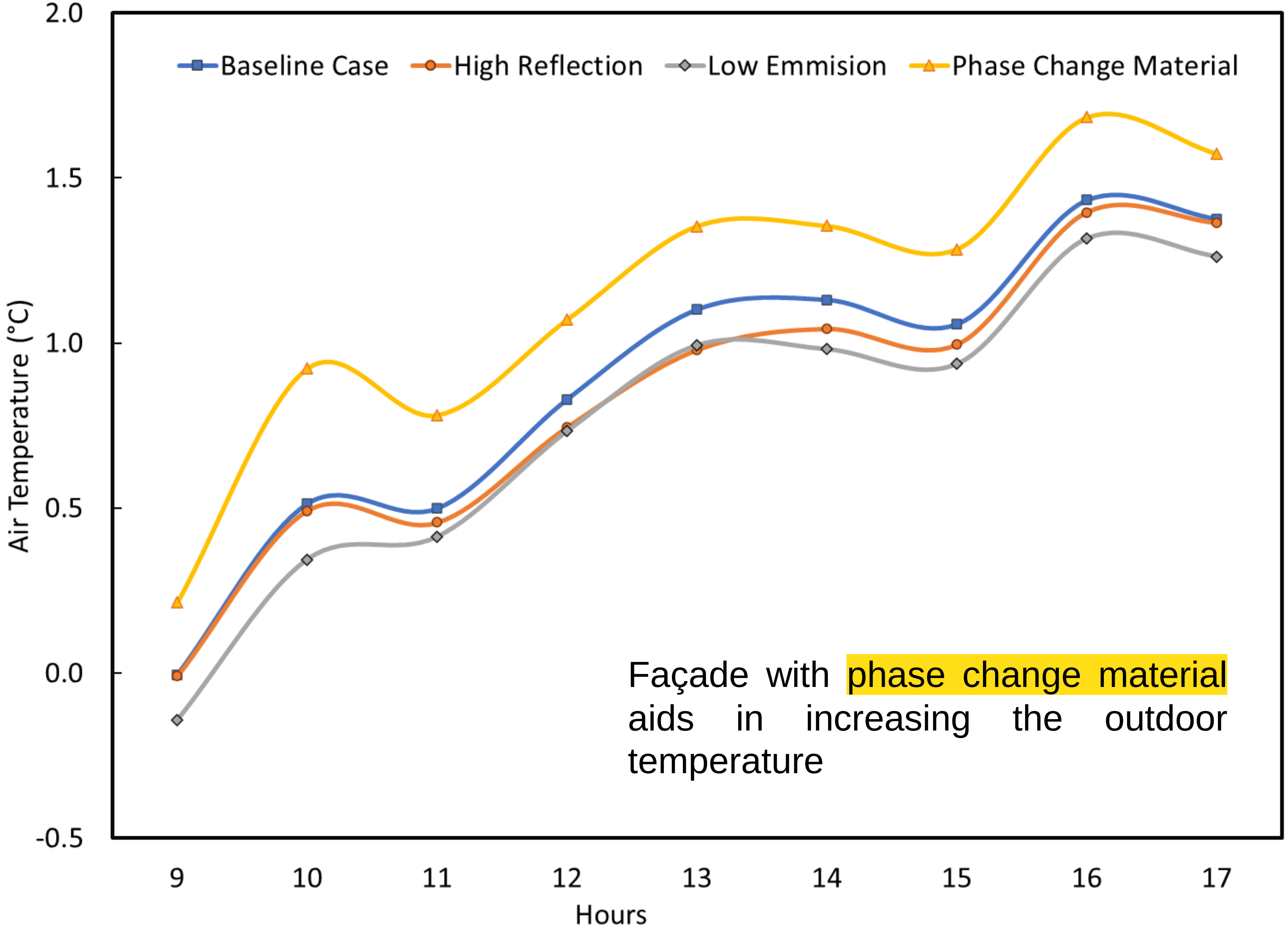


Cases	Reflectance	Emittance	Heat capacity (J/(Kg*K))
Baseline Case	0.1	0.9	850
High Reflectance	0.9	0.9	850
Low Emittance	0.1	0.1	850
PCM	0.1	0.9	4000

Representative Winter Day



Representative Winter Day



Conclusion

Summer day –

High reflectance material such as **reflective coating** aids in reducing the outdoor temperature. The maximum reduction in outdoor temperature due to this strategy is **2.0°C**.

Winter day –

Material with high specific heat capacity such as **phase change material** in the façade can aid in increasing the outdoor temperature in winter eventually increasing the thermal comfort. The maximum impact of the change is **0.4 °C**.

References

- Arshad, M., Khedher, K. M., Eid, E. M., & Aina, Y. A. (2021). Evaluation of the urban heat island over Abha-Khamis Mushait tourist resort due to rapid urbanisation in Asir, Saudi Arabia. Urban Climate, 36, 100772.
- Bienvenido-Huertas, D., Rodríguez-Álvaro, R., Moyano, J.J., Rico, F. and Marín, D., 2018. Determining the U-value of façades using the thermometric method: Potentials and limitations. Energies, 11(2), p.360.
- Bherwani, H., Singh, A. and Kumar, R., 2020. Assessment methods of urban microclimate and its parameters: A critical review to take the research from lab to land. *Urban Climate*, *34*, p.100690.
- Duran, Özlem, and Kevin J. Lomas. "Retrofitting Post-War Office Buildings: Interventions for Energy Efficiency, Improved Comfort, Productivity and Cost Reduction." Journal of Building Engineering (2021).
- Huttner, S. and Bruse, M., 2009, June. Numerical modeling of the urban climate–a preview on ENVI-met 4.0. In 7th international conference on urban climate ICUC-7, Yokohama, Japan (Vol. 29).
- Liu, Z., Cheng, W., Jim, C. Y., Morakinyo, T. E., Shi, Y., & Ng, E. (2021). Heat mitigation benefits of urban green and blue infrastructures: A systematic review of modeling techniques, validation and scenario simulation in ENVI-met V4. Building and Environment, 107939.
- Osmond, P. and Sharifi, E., 2017. Guide to urban cooling strategies. *Low Carbon Living CRC*.
- Salvati, A., Kolokotroni, M., Kotopouleas, A., Watkins, R., Giridharan, R., & Nikolopoulou, M. (2021). Impact of reflective materials on urban canyon albedo, outdoor and indoor microclimates. Building and Environment, 108459.
- Vallati, A., Vollaro, A.D.L., Golasi, I., Barchiesi, E. and Caranese, C., 2015. On the impact of urban microclimate on the energy consumption of buildings. Energy Procedia, 82, pp.506-511.
- Theeuwes, N.E., Steeneveld, G.J., Ronda, R.J., Heusinkveld, B.G. and Holtslag, A.A.M., 2012, August. Mitigation of the urban heat island effect using vegetation and water bodies. In Paper pada ICUC8–8th International Conference on Urban Climates, 6th–10th August.
- Taha, H., 1997. Urban climates and heat islands: albedo, evapotranspiration, and anthropogenic heat. Energy and buildings, 25(2), pp.99-103.
- Cheng, Y.Y., Lo, S.L., Ho, C.C., Lin, J.Y. and Yu, S.L., 2019. Field testing of porous pavement performance on runoff and temperature control in Taipei City. Water, 11(12), p.2635.

Thank you

Microclimate modelling

$$R + C + K - S = 0 \qquad \text{(Eq 1)}$$

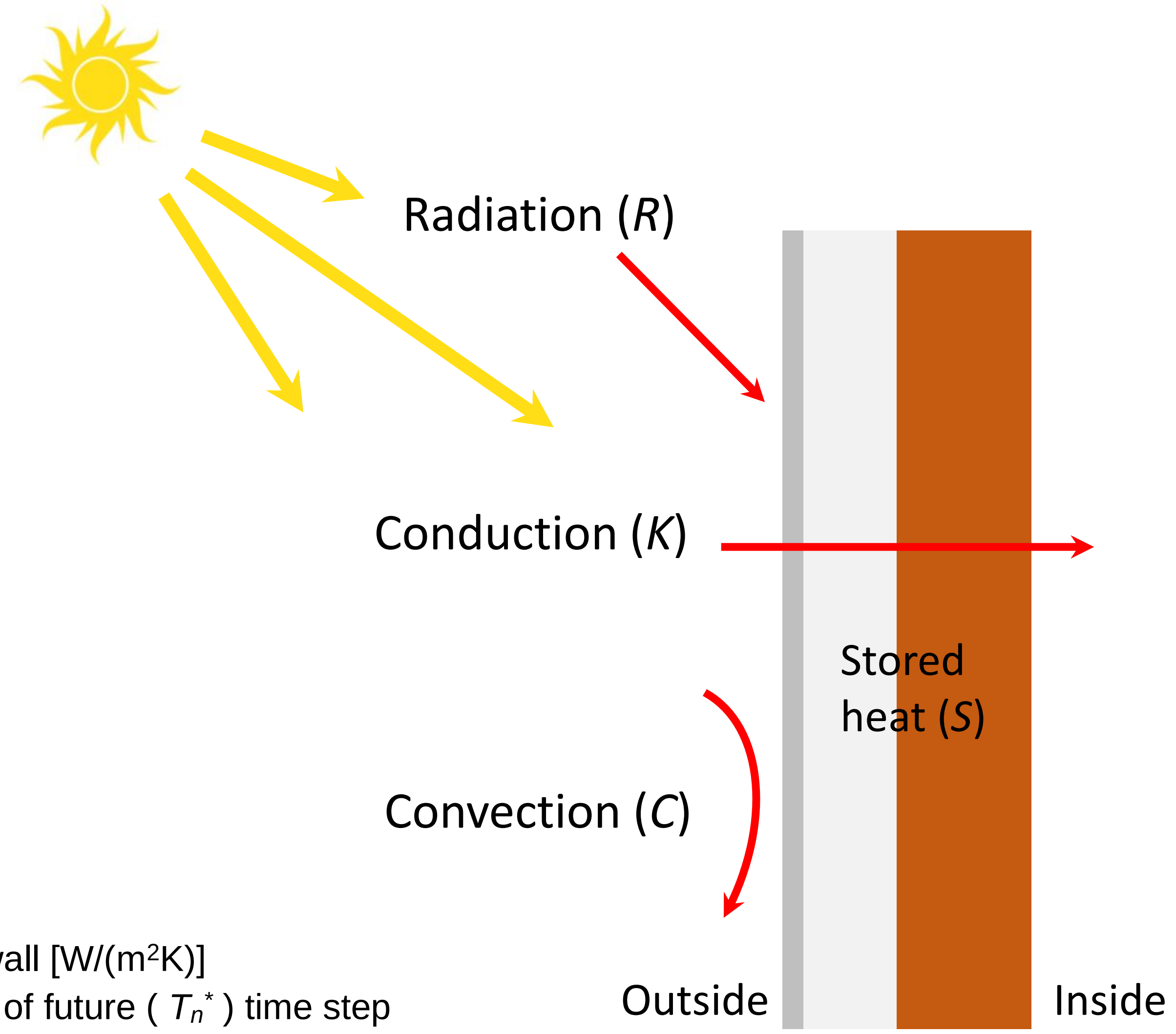
R	is the radiative heat exchange,
C	is the convective heat exchange,
K	is the conductive heat exchange,
S	is the stored heat.

$$R = Q^{abs}_{sw,net} + Q^{abs}_{lw,net} - \varepsilon\sigma T^{4}_{1,2} \qquad \text{(Eq 2)}$$

$Q^{abs}_{sw,net}$	is incoming short wave radiation [W]
$Q^{abs}_{lw,net}$	is incoming long wave radiation [W]
ε	is the emissivity [%]
σ	is the Stefan-Boltzman constant

$$C = h_{c,o}(T_{air} + T^{*}_{1}) \qquad \text{(Eq 3)}$$

$h_{c,o}$	is the convective coefficient of the outside wall [W/(m^{2}K)]
$T^{(*)}_{n}$	is the temperature at node n at present (T_n) of future (T_n^*) time step



Microclimate modelling

$$K = \frac{\lambda}{\Delta x}(T_2^* - T_1^*) \qquad \text{(Eq 4)}$$

λ is the heat transfer coefficient [w/mk)]
Δx is the distance between two nodes [m]

$$S = \frac{c_{wall}\,\rho\Delta x}{2\Delta t}\,(T_1^* - T_1) \qquad \text{(Eq 5)}$$

c_{wall} is heat capacity of the wall [J/(kgK)]
ρ Density (kg/m^3)
Δx Distance between two nodes (m)

So, equation 1 can also be elaborated using equations 2,3, 4 and 5 and can be written as

$$Q_{sw,net}^{abs} + Q_{sw,net}^{abs} - \varepsilon\sigma T_{1,2}^4 + h_{c,o}(T_{air} + T_1^*) + \frac{\lambda}{\Delta x}(T_2^* - T_1^*) = \frac{c_{wall}\,\rho\Delta x}{2\Delta t}\,(T_1^* - T_1) \qquad \text{(Eq 6)}$$