Impact of multiple urban microclimates in building performance. A simulation approach to support climate-resilient building design

Jesus Lizana[1,2], Victoria Lopez-Cabeza[1], Eduardo Diz-Mellado[1],
Carlos Rivera-Gómez[1], Carmen Galán-Marín[1]
[1]Instituto Universitario de Arquitectura y Ciencias de la Construcción, Universidad de Sevilla, Seville, Spain
[2] Instituto de Ciencia de Materiales de Sevilla, CSIC-Universidad de Sevilla, Seville, Spain

Abstract

For decades, main research attention has been paid to the energy efficiency of buildings. Computer technology and building energy simulation tools have supported the methods to compare the cost-effectiveness of energy conservation measures, which has been debated over years. However, current tools present several challenges aiming at facing future building needs under climate change and urban heat island projections. This research quantifies and demonstrates existing gaps in building simulation using a case study in Spain; and develop a holistic simulation approach to support a climate-resilience design in buildings. A case study associated with two outdoor microclimates, an inner courtyard and urban climate, was measured, simulated and validated in TRNSYS. Then, the building performance was compared with a building model facing one single outdoor weather condition. The results show that the inner courtyard was able to reduce discomfort hours by 14%, eliminating severe discomfort hours and mitigating urban overheating. Special attention should be considered in building modelling to include multi-nodal outdoor conditions to efficiently support climate-resilient design.

Key Innovations

- Gaps in building simulation
- Urban microclimate impact
- Climate-resilient building design
- Courtyard as a passive cooling solution

Research Implications

Need for building simulation with multi-nodal outdoor weather data to efficiently support climate-resilient building design. Most of the existing tools only implement the possibility of additional boundary conditions linked to temperature datasets, not considering solar gains through these building surfaces.

Introduction

Urban heat island in cities can increase the outdoor temperature by more than 5ºC (Núñez-Peiró, 2017). Moreover, previous studies have shown that the specific microclimate of inner courtyards can reduce outdoor peak temperatures by more than 8 ºC (Rivera-Gómez, 2019). These issues involve an important gap currently not considered in the building simulation. The introduction of multi-nodal outdoor conditions can enable important strategies to mitigate climate risks in the urban context, improving comfort and wellbeing in buildings.

This research quantifies the impact of buildings facing two outdoor climate conditions through a novel holistic simulation approach to improve the reliability and accuracy of the building simulation process.

Case study

A dwelling in a multi-family building in Seville (Spain) was selected as a reference case study. The indoor and outdoor temperature of the case study was monitored during summer in 2020, as illustrated in Figure 1.

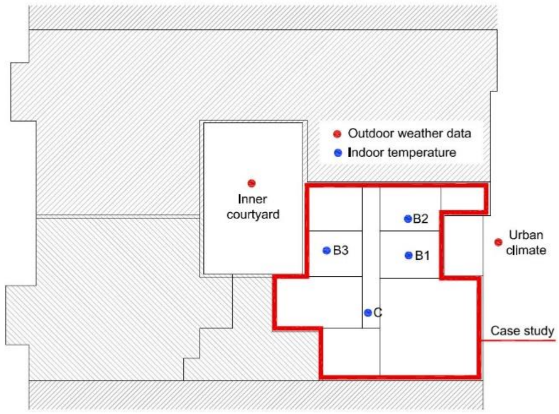

Figure 1: Selected case study with two outdoor microclimates: inner courtyard and urban climate.

Figure 2 illustrates the maximum and minimum daily temperature of the different microclimates facing the building: the inner courtyard and urban climate. The data shows that the specific microclimate of the courtyard was able to reduce peak temperatures by more than 10ºC.

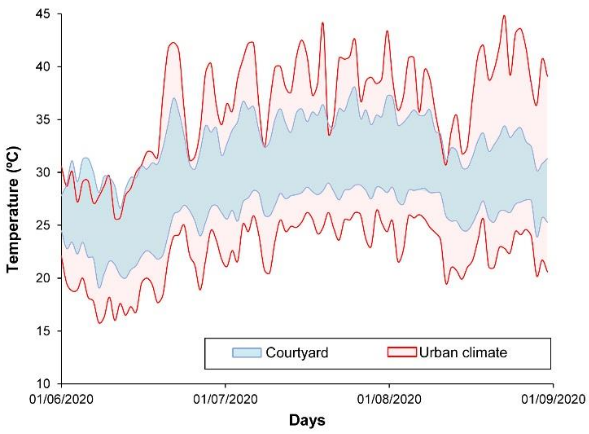

Figure 2: Differences in urban microclimates.

https://doi.org/10.26868/25222708.2021.30392

Methodology

The methodology is divided into three sections: building modelling, model validation, and indicators. Two building model scenarios are developed. Scenario 1 consists of real building case, facing two outdoor microclimates: inner courtyard and urban climate. Scenario 2 only includes urban climate.

Building modelling

The building was numerically modelled as a multi-zone in TRNSYS (Figure 3). The modelling includes geometry, external shadings, constructive elements, internal gains, infiltration, natural ventilation, thermal bridges, and internal heat capacity. Surfaces linked to the courtyard microclimate was numerically modelled as an equivalent resistance layer with a boundary condition linked to the courtyard temperature, where courtyard solar gains were previously obtained and introduced as internal radiative and convective gains per zone. Operating schedules were interactive calibrated according to building usage and measured data.

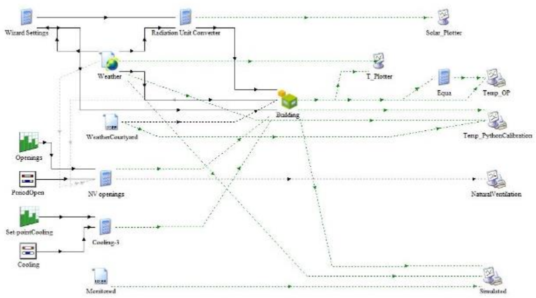

Figure 3: Building model developed in TRNSYS v18.

Model calibration and validation

The numerical model was calibrated and validated using an iterative simulation process through a python script. The statistical indices used for model validation were the Normalized Mean Bias Error (NMBE), the Coefficient of Variation of the Root Mean Square Error (CV-RMSE) and the Coefficient of determination (R^2), following ASHRAE Guideline 14 (Table 1).

Table 1: Statistical indices for model validation.

	NMBE	(CV)RMSE	R2
Bedroom1 (B1)	-0.020	0.039	0.77
Bedroom2 (B2)	-0.005	0.020	0.93
Bedroom3 (B3)	-0.015	0.030	0.84
Corridor (C)	-0.012	0.035	0.76

Building performance indicators

The building performance was evaluated through the adaptive thermal comfort model (EN 16798-1:2019) during the heat period from 10/06/2020 to 20/08/2020. The performance of scenarios was compared through the discomfort hours by each comfort category (I, II and III).

Results and discussion

Figure 4 shows the results of scenario 1 and 2 according to the European adaptive comfort model. Indoor operative temperature values are lower in scenario 1 due to the benefit of courtyard microclimate, which is able to mitigate urban overheating. This courtyard benefit results a promising passive cooling strategy for buildings.

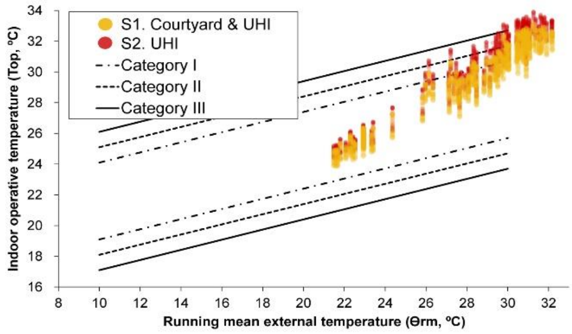

Figure 4: Comfort model based on EN 16798-1:2019.

Figure 5 quantifies the percentage of discomfort hours per each comfort category (I, II and II). The results show that the inner courtyard was able to reduce discomfort hours by 14%, eliminating most of the severe discomfort hours (DH > Cat III) and mitigating urban overheating.

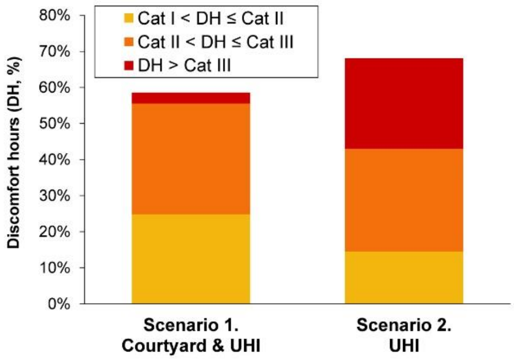

Figure 5: Discomfort hours based on the adaptive comfort model defined by EN 16798-1:2019.

Conclusion

This research quantifies the impact of multiple outdoor microclimates on building performance. A case study facing an inner courtyard and urban climate was measured, simulated, and validated in TRNSYS, and the results were compared with one single outdoor condition. The results highlight how specific urban microclimates can reduce discomfort hours by 14%, eliminating severe discomfort periods. Special attention should be considered in building simulation to include multiple outdoor microclimates to support climate-resilient design.

Acknowledgement

Work supported by the Spanish Government through the project RTI2018-093521-B-C33 and postdoctoral fellowship to J. Lizana (FJC2019).

References

Núñez-Peiró, M. (2017). Update of the Urban Heat Island of Madrid and Its Influence on the Building's Energy Simulation. In Sustain Dev Renov Archit Urban Eng.

Rivera-Gómez, C. et al. (2019). Tempering potential-based evaluation of the courtyard microclimate as a combined function of aspect ratio and outdoor temperature. *Sustain Cities Soc*, *51*, 101740.

EN 16798-1:2019. Energy performance of buildings. Ventilation for buildings. Part 1.

https://doi.org/10.26868/25222708.2021.30392