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Chapter 69
Climate Adaptation in Urban Regeneration: A Cross-Scale Digital Design Workflow

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Abstract Urban vulnerability has many facets. Among these, urban texture and plot pattern, building massing and density, greatly affect the microclimate. Thence, redefining urban regeneration design criteria for climate neutrality is crucial, including environmental factors in the design process at different scales. In the light of climate change, despite this urgent call, adaptive design approaches useful to assess trade-offs between urban regeneration scenarios and microclimate quality are lacking. This paper introduces a novel digital design workflow that integrates climate quality and associated indicators in urban and building design, adopting a cross-scale approach. The main goal is to increase the resilience of the built environment in the foresight of future scenarios, by promoting climate-sensitive design solutions. Environmental performances were analysed using digital tools and implemented in a design workflow, allowing urban microclimate analysis. Performance metrics were calculated using Urban Weather Generator and Energy Plus. With the former tool a climate performance comparative study has been run in different scenarios, by varying morphological parameters and computing the intensity of the Urban Heat Island. While, Energy Plus was used to simulate the impact of building form and UHI on building energy demand, highlighting the interdependence of different design scales and addressing optimal building performance. The results provide additional levels of knowledge, both in terms of analysis and design scenario evaluation: urban metrics and climate impacts, building form and envelope design, adaptation solutions. This workflow is tested and a scenario suitability for the Mediterranean city is shown, exploiting the research-by-design transformations of 22@ Innovation District of Barcelona. The paper highlights the correlation between microclimate

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and design solutions and lays the foundations for a climate/design cross-talk to help policymakers and practitioners achieve urban climate adaptation goals.

Keywords Adaptive design · Urban microclimate · Climate change · Urban vulnerability

69.1 Introduction

Dense cities expose people to different kinds of climate vulnerabilities: extreme events, concentration of inhabitants in risk-prone areas, inadequate buildings and many others.

This is why research attention on spatial configuration and physical features of cities has recently risen in various disciplines, including geography, urban ecology, urban and environmental design, building design, urban climatology and building physics (Erell 2012). As a reaction to the demanding need to mitigate climate change and the ecological impact of the built environment, in order to adapt to inevitable consequences and promote health and well-being, research efforts have focused on the unintended interaction among cities' physical characteristics, microclimate and energy balance with a diagnostic or design perspective (Lenzholer 2015; Stewart and Oke 2012). This led to a number of relevant changes in the design discourse and structure—both in term of process and method—and contributed to highlight the key elements for the decisions about the main enforcement actions to be included in urban regeneration design process (Morganti and Rogora 2021).

However, this subject is still fragmented: studies hardly reach comprehensive outcomes due to the complexity of the above-mentioned interaction in the built environment and to the lack of skilled scholars and professionals. By consequence, practical application in urban regeneration process remains limited.

The present study proposes and discusses a novel digital design workflow (Fig. 69.1) that integrates urban climate quality and associated indicators in urban and architectural design, adopting a cross-scale approach. The novelty of the study lies in permitting architects to analyse environmental performance and to take evidence-based urban and building design choices. The main goal is to help architects and urban designers to easily control climate and energy parameters, impacts and associated urban vulnerability trough well-known digital tools.

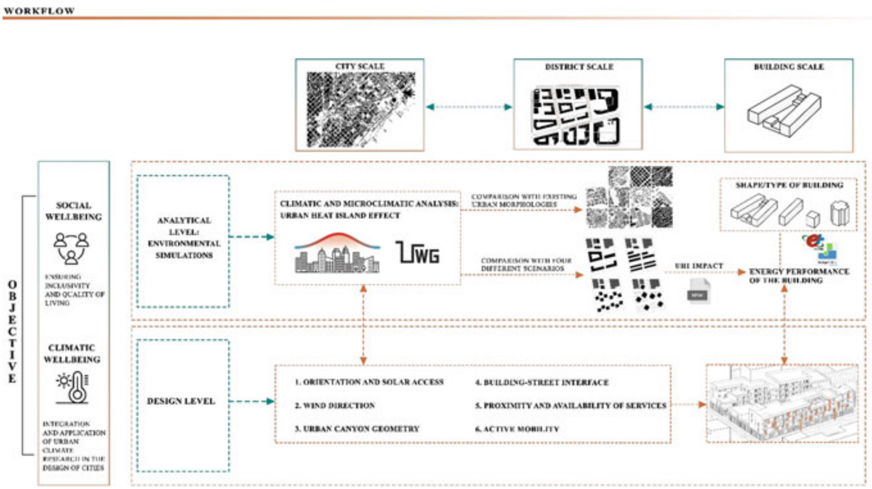


Fig. 69.1 Visual representation of the workflow

69.2 Materials and Method

69.2.1 Analytical and Design Approach

The design process has been supported by the workflow in Fig. 69.2. It is articulated by running both the analytical process of environmental simulations and the design process. The analyses were executed through digital tools. The main objective was to validate the current state of the art about the impact of certain specific parameters on the urban microclimate performance, crossing different scales: the neighbourhood, the district, the island and the building. The impact of urban morphology at neighbourhood level on urban microclimate and UHI was investigated, by focusing on the influence of building typology and form to heating and cooling demand in the Mediterranean climate.

69.2.2 Case Study

A regeneration project of an urban area of 22@ Innovation district of Poblenou in Barcelona has been used as case study to test the novel digital design workflow (Fig. 69.2). The project area is about 8 hectares and currently characterized by a limited number of low-energy efficiency housings, scattered across industrial buildings. The reference scenario is tested by exploiting the research-by-design transformations of the above-mentioned project area. Four different scenarios are presented to compare in detail at both neighbourhood and building scale.

Fig. 69.2 Current state (top) and masterplan (bottom) of the project area

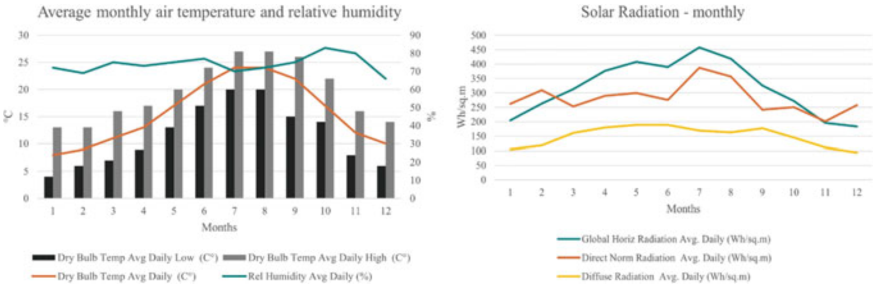


Fig. 69.3 Climatic conditions of Barcelona (based on Barcelona 081,810 IWEC EPW file). Average monthly air temperature and relative humidity values (left); monthly average daily Solar Radiation values (right)

69.2.3 Climate and Microclimate Evaluation

These sections describe how climate and microclimate were studied and the metrics used to compare different scenarios. The study mainly covers the summer period, during which the urban fabric's morphological characteristics influence the urban heat island most significantly. A preliminary analysis was carried out on the Mediterranean climate of Barcelona, characterised by hot, dry summers (Csa Koppen-Geiger climate classification), shown in Fig. 69.3. The analysed climate data from Barcelona El Prat airport will later be considered as rural station data for the urban heat island analysis. The typical climate presents relatively high average outdoor temperatures throughout the year (average annual temperature 16°), and a rather high average annual relative humidity of 73%, due to the proximity of the sea.

69.2.4 UHI District Scale

The effect that the regenerative design of the case study's urban area has on the urban heat island was assessed using Urban Weather Generator (Bueno et al. 2012). The UWG algorithm evaluates the difference in temperatures between a rural context and the urban canopy layer; the UWG calculation tool has already been validated for Barcelona's climate in previous researches (Salvati et al., 2019). The 'rural' EPW climate weather file, which provides the meteorological inputs, was taken from EnergyPlus weather data (Barcelona 081810 IWEC), and includes climate data from Barcelona El Prat airport (Elev. 4 m, 41.33 °N, 2.1 °E). The 3D model of the project was used to provide the morphological input parameters (Fig. 69.4). Table 69.1 lists the input variables that were customised, while others, such as the traffic-sensitive heat flux, kept their default values.

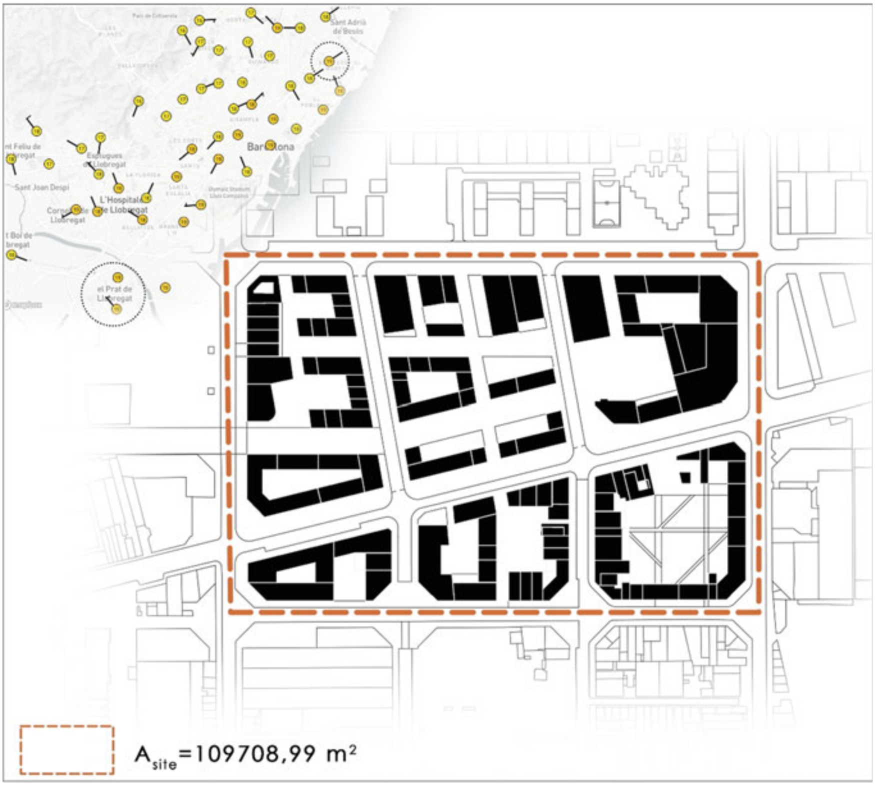


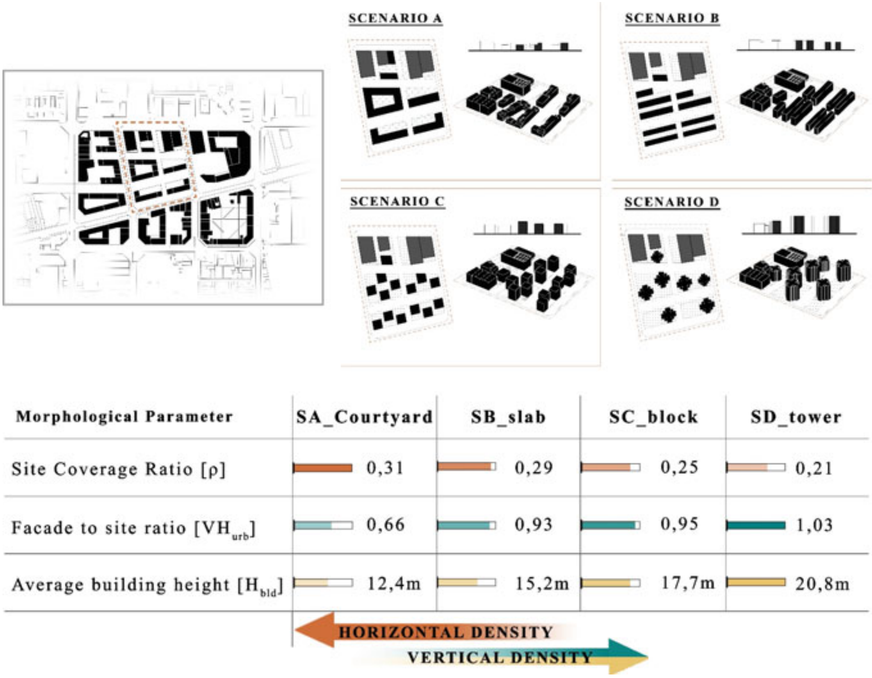
Fig. 69.4 Analysed scenario—district scale

Table 69.1 Customized input UWG parameters

Variable	UWG parameter	Definition	Value
Urban morphology	Site coverage ratio [ρ_{urb}]	Ratio of building footprint to the site area [–]	0.35
	Façade to site ratio [VH_{urb}]	Ratio of the vertical external surface area to the site area [–]	0.64
	Average building height [H_{bld}]	Average building height normalized by building footprint [m]	12.8
Vegetation cover	Urban area veg. coverage	Ratio of vegetation coverage in the urban area to the site area [%]	0.26
Surface albedo	Road albedo	Ratio of reflected radiation from surface to incident radiation upon it [–]	0.15

69.2.5 UHI Island Scale—Comparative Analysis

The UHI effect has been evaluated to compare four different scenarios of an island in the project area. The three alternative scenarios, against which the SA_Courtyard has been cross-referenced, were created, by varying the morphology of the urban fabric, and by fixing the built-up cubature at about 112.000 m^3 (as in the reference block), as shown in Fig. 69.5. The single island was assumed to repeat homogeneously over an area of 1 km × 1 km, and we focused on the impact that the variation of morphological parameters alone (Site coverage, Façade to site ratio, Average building height) can have on the UHI in the Mediterranean context. (Salvati et al., 2019) This comparison was central to validate how different urban forms display different climatic performances, and to prove that some morphological parameters have a more negative effect on the UHI than others.



Morphological Parameter	SA_Courtyard	SB_slab	SC_block	SD_tower
Site Coverage Ratio [ρ]	0,31	0,29	0,25	0,21
Facade to site ratio [VH_{urb}]	0,66	0,93	0,95	1,03
Average building height [H_{bld}]	12,4m	15,2m	17,7m	20,8m

Fig. 69.5 Framework of the city block (top left); visual representation of four different alternative urban fabric (top right); values of the morphological parameters used for calculating the UHI (bottom)

69.2.6 Energy Demand—Building Scale

Moving to the building scale, a courtyard residential building from the reference model was studied and designed in further detail. A comparative analysis of the energy demand for heating and cooling was carried out using EnergyPlus software. Three alternative building types for the courtyard one, based on existing building plans (linear block, low-rise block, high-rise tower) has been computed (Fig. 69.6), highlighting the interdependence of different design scales and addressing optimal building performances. The typologies have been put in their urban context of the four scenarios used for the UHI assessment, by inserting, as input climate data for each scenario modified running UWG from the rural one of Barcelona El Prat airport. The study has a comparative purpose, and it does not constitute an absolute assessment of energy demand, since some factors that have been kept by default or not taken into account. Table 69.2 shows the input values: in modelling the scenarios, the shape (compactness) and window-to-wall ratio parameters were varied, while keeping constant the envelope performance, the activity and the HVAC templates set to the standard values for residential buildings by the *Código Técnico de la Edificación* (Ministerio de Fomento 2017).

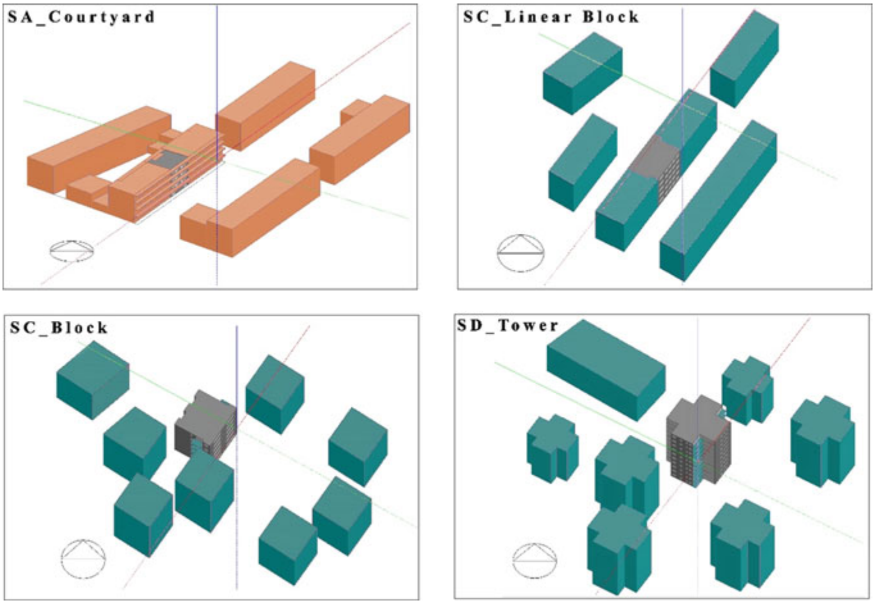


Fig. 69.6 Visual representation of the four scenarios modelled in DesignBuilder

Table 69.2 Building scale analysis input parameter

	Variable parameters		Fixed parameters	
Test cases	Compactness Index	Window-to-wall ratio (%)	U-CLT structural wall (W/m^{2}K)	U-ventilated roof (W/m^{2}K)
SA_COURTYARD	0.66	30.27	0.28	0.25
SB_SLAB	0.72	31.28		
SC_BLOCK	0.74	21.82		
SD_TOWER	0.64	42.86		

69.3 Results and Discussion

The new urban layout has been planned with mixed uses, large amounts of public open spaces and permeable surfaces. This ensures outdoor and indoor comfort and the availability of spaces that inhabitants can use as climate shelters to cope with the increasingly uncomfortable and risky conditions caused by climate change (Taleghani, 2018). The block becomes very permeable to pedestrians and large bicycles. Besides, pedestrian paths are designed to encourage active mobility and the strategic location of services, so as to have attractive, safe and always active streets in the neighbourhood.

69.3.1 UHI—District Scale

The average values of summer and winter UHI, for the transformed project area, are quite low, respectively, 0.9 for the average summer UHI (month of July) and 1.0 average winter UHI (month of January). The summer UHI has been further investigated, since for the Mediterranean climate the UHI in the warm months, as demonstrated in other studies (Natanian and Auer 2020), has more evident effects, including on the energy performance of the building. In July, the hottest month in the city of Barcelona, a maximum average UHI value of 1.4 is reached at midnight. These values were benchmarked by running UWG with input parameters given by the average values of 10 existing urban fabrics taken from the study by (Salvati et al., 2019). The baseline model has well higher average summer and winter UHI values than the new urban settlement, 2.2 summer UHI and 1.5 winter UHI, respectively, as shown in Fig. 69.7.

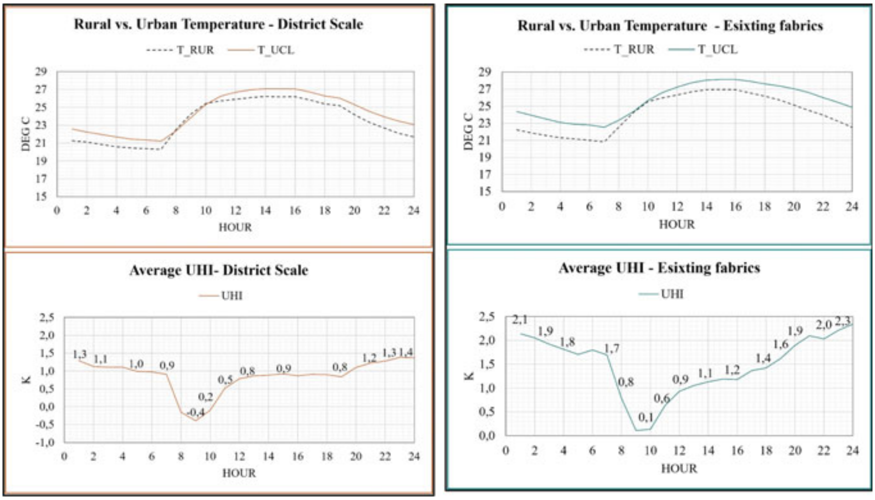


Fig. 69.7 UWG output graphs July UHI analysis: transformed urban area at district scale (top) and baseline model of existing urban fabrics (bottom)

69.3.2 UHI—Island Scale

With the input parameters of Fig. 69.5, we obtain the summer and winter average UHI values reported in Table 69.3. The values refer to low ranges of UHI having all low compactness index fabrics, it is noticeable how, in particular for summer, UHI confirms what has been already proved in other studies: the increase of vertical density (more façade surfaces) in Mediterranean climate contexts, due to the phenomenon of multiple reflections of radiation between surfaces in Urban Canyons, impacts on UHI via the causation of temperatures higher than those in other scenarios, where vertical density is lower.

To verify this trend, the UHI values of the four scenarios were also compared to those provided by the graphical tools created for different mean heights in the study by Salvati et al. 2019. In these diagrams, the UHI values are only reported based on the variation of the morphological facings (ρ_{urb}, VH_{urb}, H_{bld}). In the UHI values provided by the diagrams, there is a more direct and linear correspondence between

Table 69.3 Average UHI values in the four different scenarios

Scenarios	UHI winter UWG	UHI summer UWG	UHI winter graphic	UHI summer graphic
SA_PROJECT	1.00	0.8	0.8	0.8
SB_SLAB	0.9	1.1	1.2	0.8
SC_BLOCK	1.0	1.0	1.5	0.8
SD_TOWER	0.9	1.3	1.6	1.0

the increase of vertical density and summer UHI, and the same output as in the UWG simulation is not available, as the diagrams were created neglecting the parameters of vegetation and tree coverage, albedo of the surfaces. In both evaluations, the less dense urban plot with tower buildings is the one with the highest UHI values, as it has more façade area. On the other side, the project case study with courtyard building typology has the lowest values in both seasons.

69.3.3 Energy Demand

Figure 69.8 shows the results of the analysis of the heating and cooling demand of the buildings of the various case studies, compared with the respective compactness coefficients calculated as

$$\mathrm{Rc} = \mathrm{Se}\frac{\mathrm{Se}}{\mathrm{Sg}}4836\frac{\mathrm{Vt}^{\frac{2}{3}}}{\mathrm{Sg}} \tag{69.1}$$

which refers to the equivalent surface of a sphere with the same volume as the building (Serra and Coch 1995) and the window-to-wall ratio. Since the intention was to focus mainly on the effect of building morphology urban fabric on the building's energy performance, the presence of any shading devices on the windows was not taken

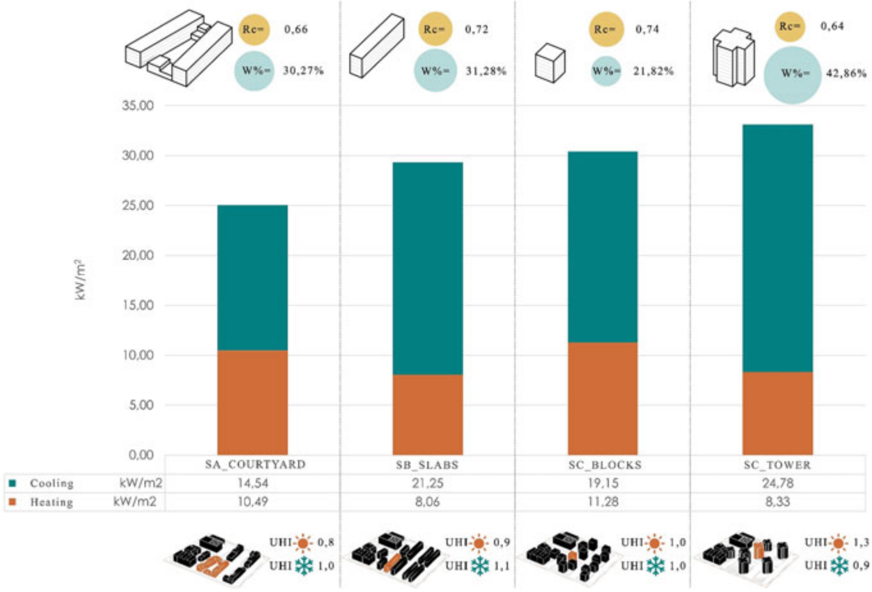


Fig. 69.8 Annual heating and cooling demand (kW/m^2), compactness index, window-to-wall ratio (%), and the average values of summer and winter UHI for the four different scenarios

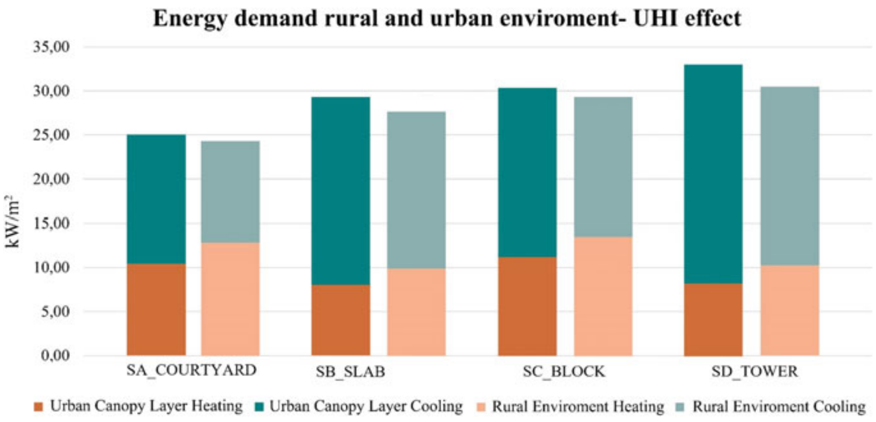


Fig. 69.9 Comparison between annual cooling and heating demand of the four scenarios with and without the effect of the UHI

into account, as this would have considerably modified the results. The courtyard type clearly has the lowest overall annual demand, which result is obtained despite the high values of heating demand with respect to the other buildings, thanks to the lower cooling demand in the summer months. It is evident that there is a more direct relationship between energy performance and the amount of glazed surfaces than between the former and of the compactness index, as already shown by Premrov et al. 2016. The tower typology has the highest cooling demand due to the heat entering from the large number of windows, considered without shading, which in return in the winter months provide high solar gains and therefore a lower heating demand.

69.3.4 *Rural and Urban Energy Demand*

By running the four simulations with the climate data of Barcelona airport as well, it is possible to see in the graph in Fig. 69.9 the gap between the rural and the urban context which is influenced by the UHI. It can be seen that the benefits in winter due to the higher external temperatures of the rural contexts are in any case lower than the energy surplus required in the summer months for the cooling system.

69.4 Conclusions

Through the workflow described above, an urban regeneration project was developed in the Mediterranean urban climatic context, which, in parallel, acted as a case study for several climatic and microclimatic analyses, focusing in particular on the effects of the urban heat island phenomenon, calculated with the validated UWG tool. By carrying out comparative analyses with other scenarios, different in morphology from the reference one, the influence trend of some morphological variables on the built environment's energy performance has been verified at district, island and building scale. The results suggested that, during the summer period, urban layout with courtyard buildings of low average height is to be preferred over other types of fabrics, which have higher 'vertical density' and contribute to the increase of temperatures in cities, particularly at night. Turning to the building scale, it has been further verified that regenerative design must have a holistic and cross-scale approach given the interdependence of the effects that these different levels have on climatic well-being.

The importance of this type of study is related to the fact that in the preliminary stages of planning and design, the choices that most affect the quality of the space and environmental and the energy performances of buildings are concentrated. For instance, those about the shape of buildings and of urban layout are increasingly difficult to modify as design advances. The study contributes to foster the integration of scientific knowledge on urban climatology and sustainability of urban systems into the planning and design practices for densification and/or regeneration of existing urban areas. Through the use of available digital tools for climate and microclimate assessments, it allows for an integrated, cross-scale control of the design process. This workflow can be considered reliable for a pre-design phase, while for more detailed analyses, it needs further integrations and other tools. A limitation also lies in the reliance on different digital tools that require parallel 3D model creation on different software, without being able to use a single digital graphic interface during the overall analysis development.

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