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Embodying Climate Change

URBAN PLANNING – ARCHITECTURAL REPORT ON THERMAL STRESS IN THE CITY OF MADRID

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Urban planning/architectural report on thermal stress in the city of Madrid 2021

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Abstract

This report serves the EmCliC research project (*Embodying Climate Change*) as an analysis on the influence of architecture and urban planning on the experiences of thermal stress in the city of Madrid. It reviews the existing bibliography on the role of the urban fabric on the Urban Heat Island effect, with special focus on the different building typologies, construction solutions, materials, urban blue infrastructure or presence of green areas. This work, in addition, aims to offer a broad vision that is not restricted to the technical, but that values social, political and cultural issues as relevant elements when analyzing the relationship of the architecture of the city with overheating and, consequently, with the Climate Change. Thermal performance of the city, is integrated in this study in a broader ecosystem of interests, policies, regulations and projects, as well as in its "built" history.

With that goal, the analysis focuses on the situated and embodied experiences of thermal stress, from the point of view of architecture and urban planning. The object of study, therefore, will be the Urban Heat Island (UHI). The methodology will be to reinterpret the UHI of Madrid, basing on the given cartographies, but attending to more specific and embodied conditions. Therefore, the UHI will not be only be analyzed as a shape that covers the city, but as something more concrete, that is dependent on specific and situated assemblages of heterogeneous phenomena such as urban density, presence - or absence- of air currents, thermal buffers, radiant surfaces, the actions of neighbors, or bioclimatic ordinances.

Keywords

Urban Heat Island, Climate Change, urbanism, architecture, overheating

Introduction

Madrid, historically, is one of the European cities with the highest incidence of heat waves (Guerrero et al., 2018). The transformations of the territory and the urbanization process of the city favor a local climate, exacerbating the effects of overheating in summer and generating the so-called UHI effect. Furthermore, greater effects of Climate Change are expected (European Environment Agency, 2012) in the interior of the Iberian Peninsula, producing more need for air conditioning systems in the summer and, consequently, increasing emissions of greenhouse gases into the atmosphere of the city. In addition, the city of Madrid has a high number of vulnerable inhabitants, especially sensitive to thermal stress (Larriva and Higueras, 2020). The influence of the built city on the UHI effect is a matter not yet sufficiently studied. So much so, that in the energy evaluation of buildings in Spain - compulsory for all dwellings - the climatic data of the urban environment is not integrated, but rather generic models of territorial climate, with values closer to the rural environment. Only some initiatives and research have tried in recent years to generate models reflecting the specific thermal conditions in the city (Nuñez Peiró et al, 2016). Other studies also focus on drawing Madrid's UHI through measurements and geolocation of its extension (Nuñez Peiró et al, 2017, Fernandez et al, 2016). Such works carry out the important task of detecting the size and performance of the phenomenon. However, there are still not enough contributions that evaluate its origins, or analyze the historical and actual urbanization practices of the city by tracing the formation of urban fabric and building typologies. We can find academic research that evaluate districts in detail, based on variables influencing thermal stress, such as orientation, construction qualities, year of construction (Martín Consuegra et al, 2018), surface albedo, presence of water and / or trees, etc. (Tumini, 2013), but we still have not found analysis of the mitigating and aggravating factors of urban overheating that successfully place such elements in the urban fabric. An exhaustive analysis of these variables would be of great interest, but it exceeds the scope of the present report. What is presented here is intended to serve as a basepoint to evaluate, from the point of view of heat management, the urban and building practices of the city.

This document starts from the hypothesis that the Heat Island, as a dynamic phenomenon, can be better described as an assemblage in which the built environment participates at various forms and scales. With the aim of carrying out a cross reading of the city - from buildings to urban policy, paying attention to adaptation measures - it is developed in three sections: 1- climatic and built context, 2- adaptation to overheating and 3- public policies.

The first chapter - *Comfort and thermal stress in Madrid* – defines the basic notions of thermal comfort, as well as the impact of buildings on heat and energy management. The most relevant parameters in relation to comfort and thermal stress are exposed, and what are the actions that, from the architecture, deal with them. Variables of discomfort or thermal stress that may be present inside dwellings are also explained, such as radiant asymmetries or air streams. The chapter also focuses on heat transfer mechanisms and notions about how the building acts to limit or enhance them. It also details the regulations and mandatory standards for thermal comfort in Spain, with an emphasis on the precise moment of their appearance.

After explaining this framework, the chapter analyses the different historical developments of the city and the building typologies and construction systems, assessing their thermal performance and their degree of vulnerability to overheating. With that purpose, it gathers and presents the available information on Madrid's UHI. In this first chapter we will obtain a transversal answer to the question: *what is the current situation on urban overheating and thermal stress in Madrid?*

In the second chapter - *Urban and architectural adaptation to thermal stress in Madrid* – the goal is to identify those heat-mitigating practices that are being tested in the city of Madrid. The chapter is structured in a decreasing order of scales: starting with the *urban scale*, moving towards the *architectural scale* and ending with the *user scale*. Each scale engages one type of climate adaptation action. Thus, the urban scale transfers adaptive practices through regulations, the architectural scale through bioclimatic design, and the user scale through daily and concrete actions and routines. The sum and superposition of scales allows us to glimpse a city that deals with thermal stress, and allows us to intuit the contour of the UHI, which is located unevenly in neighborhoods, streets and buildings.

The third chapter – *Policies for the adaptation to thermal stress in Madrid* – analyses those measures, laws, plans and strategies that, in the city of Madrid, deal with the issues of urban overheating. Here, after identifying the framework of EU objectives, directives and regulations, and briefly exposing the Spanish agenda on Climate Change, the chapter addresses different municipal initiatives. By using a critical approach, that arises from the previous analysis, the objective is to offer a detailed review of their adequacy when it comes to minimizing the effects of thermal stress on the city. After that, deeper attention is dedicated to those local plans gear towards the community that is object of study of the EmCliC project: the elderly.

Finally, the report is completed with a last section in which the conclusions from the analysis are compiled, as well as possible areas of development for future research any entity interested in the influence of architecture and urban planning on thermal stress in Madrid.

Chapter 1.

Comfort and thermal stress in Madrid

1.1 Definitions of comfort and thermal stress: standards, building performance and technical regulations.

When analyzing heat stress in the city, it is necessary to dwell on the definitions and methods by which comfort values are established inside buildings. International standards, which rule the evaluation methods for indoor thermal comfort, define thermal comfort as “that mental condition that expresses satisfaction with the thermal environment and that is subjectively evaluated” (ASHRAE 55-2017). Thermal comfort is related to values of air temperature, relative humidity, radiant temperature of interior surfaces and air speed. Similarly, discomfort or, when it is very high, thermal stress, is caused by inadequate values of such parameters, as well as by "local conditions such as vertical differences in temperature between the feet and the head or large asymmetries of radiant temperatures" (ASHRAE 55-2017). The ISO 7730 standard, which defines the values and methods for calculating comfort inside homes, determines that “the most common cause of local discomfort is air currents. Discomfort can also be due to abnormally high temperature differences between the head and feet, floors that are too cold or hot, or large asymmetries in radiant temperature” (ISO 7730).

The interior conditions of comfort or thermal stress -when the body’s means of controlling its internal temperature starts to fail- are determined, therefore, by a series of variables in which the construction itself interferes. Among those variables, the dry temperature and the relative humidity stand out, followed by the air velocity and average radiant temperature of interior surfaces. Variables that are beyond “architectural” control, but still impact people’s experiences, include individual’s metabolic rate - the activity being carried out- and their degree of clothing.

ISO 7730 standard uses a subjective evaluation methodology to predict peoples’ hygrothermal comfort levels inside buildings. The grade of satisfaction is determined as depending on the set of optimal parameters that include dry bulb temperature, mean radiant temperature, air velocity, humidity, clothing level or metabolic rate. Using the PMV (Predictable Medium Vote) and PPD (Predicted Percentage of Dissatisfied) values, comfort conditions are determined. These two values determine what people would vote and feel when exposed to specific indoor higrothermal conditions.

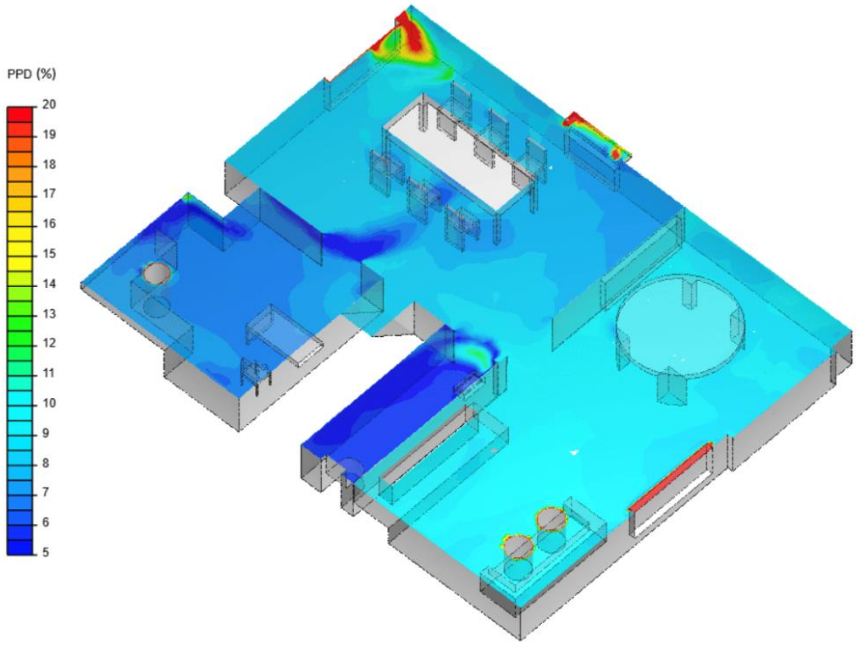


Figure 1. PPD inside a conventional flat. According to ISO 7730 and ASHRAE 55 all areas should be kept below 20%. This means that under 20% of the people would feel dissatisfied by the thermal conditions. https://www.simscale.com/blog/2019/09/what-is-pmv-ppd/

Architecture practice is committed to fulfill thermal comfort standards inside the buildings. We find what is called *bioclimatic design*, which tries to ensure interior comfort conditions in homes -or buildings for other uses- by taking into account the surrounding climatic conditions (sun, rain, prevailing winds, presence of vegetation ...) and incorporating them to the building's thermal performance. The objective is that the building itself performs passively, that is, without adding extra energy, to provide the conditions closest to comfort. Thus, for homes whose bioclimatic design is poor or non-existent, they will need a lot of energy to satisfy the hygrothermal needs of their occupants. If this energy is not renewable, they will be considered inefficient homes with poor energy performance.

One of the cornerstones of bioclimatic design is the Olgyay chart which, supplemented years later by Givoni's chart, are considered two of the most important tools when defining and measuring design strategies geared towards thermal comfort. Both are very useful when defining and forecasting the interior sensation of a building based on climatic parameters such as temperature, relative humidity, or air speed. And, for the purposes of the present study, they are very useful when laying a conceptual framework on comfort and thermal stress, and also explaining how other variables - in addition to temperature - become fundamental to determine these conditions.

Thus, we can observe how, in Givoni's chart, there is a horizontal axis –for dry bulb temperature - and a vertical axis -for absolute humidity - between which increasing curves run from left to right, which correspond to the values of relative humidity. If we look at the methods for defining climatic comfort (ISO 7730 or ASHRAE 55), the values for which thermal comfort for humans is situated are settle in a range between 20ºC and 27ºC for temperature, 20 to 80% for relative humidity, being the comfort temperature of 24ºC and relative humidity of 50% in a generic way. Of course, these numbers can vary according to different climates. Also, these values are variable depending on the approach to the concept of comfort, which can be understood statically (Fanger, 1970) or dynamically (Humphrey, 1978). In dynamic methods -which take the outdoor temperature values of the last days in their calculation- the comfort values vary remarkably from one day to another (Sanchez et al. 2017). Meaning that, even in a specific location, humans tend to adapt to outdoors temperature. Comfort is, therefore, a variable and a subjective concept.

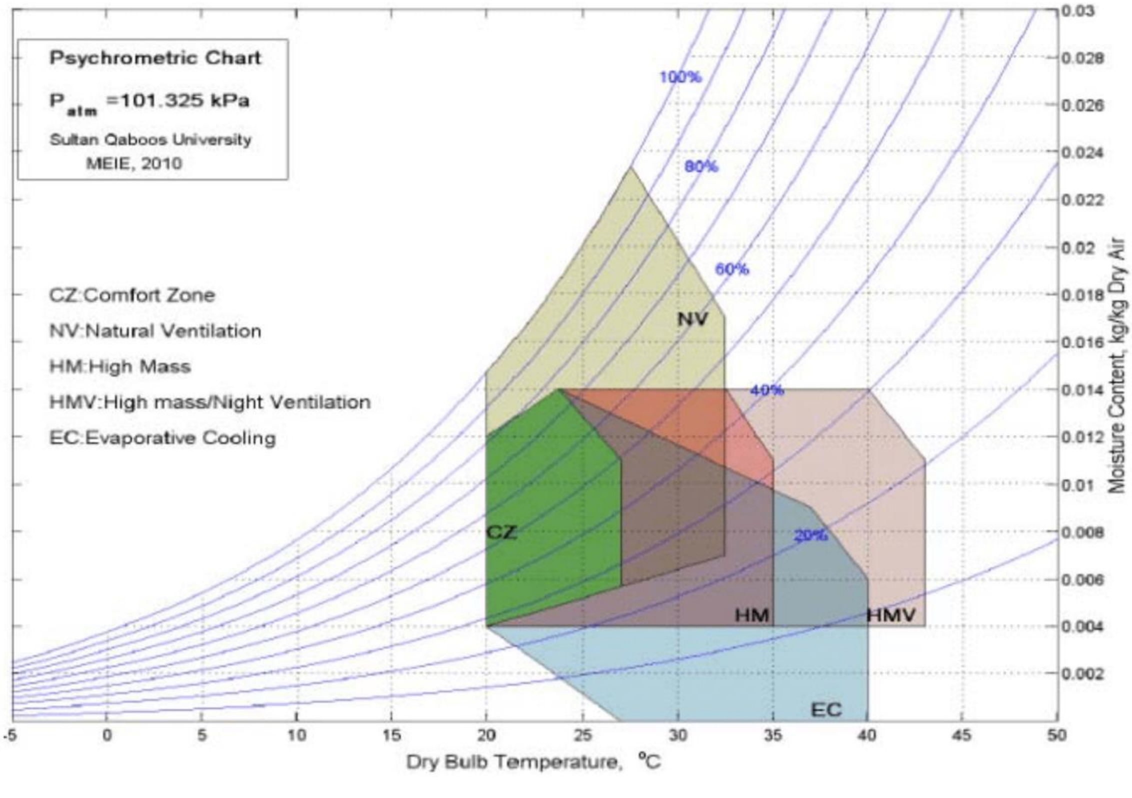


Figure 2. Givoni’s Chart.

https://www.researchgate.net/figure/Givonis-Bbioclimatic-Chart-Plotted-From-Givonis-Chart-Data_fig4_253337713

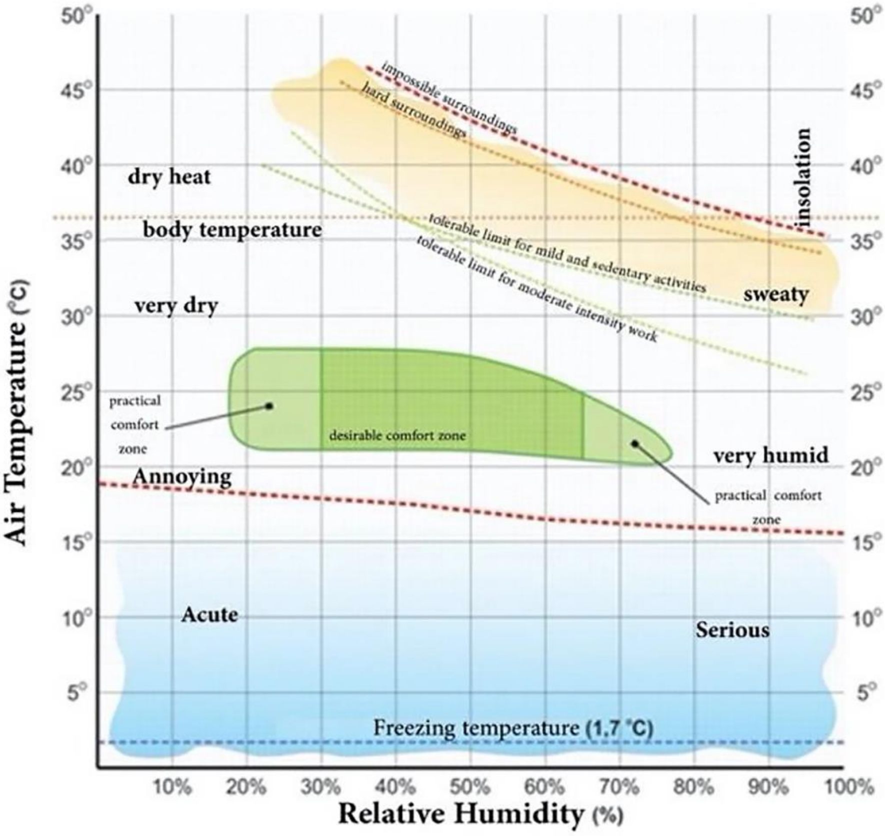


Figure 3. Olgyay's Chart.

https://link.springer.com/article/10.1007/s10098-021-02158-0

Architecture, therefore, transforms the parameters of temperature and humidity that are present in the environment to accommodate them to the needs of interior comfort. To do so, it uses passive systems (control of solar heating through windows, for example, or the insulation of the enclosures themselves) and active systems (air conditioning refrigeration systems, for example). All these mechanisms are computable by means of energy loads, which will be positive if the room/building is being heated up and negative if the heat is being lost towards the outside of the room/building (Figure 4). Thus, in calculating the energy performance of homes, in which the different heating and cooling loads are evaluated, in order to maintain a space in optimal conditions of thermal comfort, the whole variety of heating or cooling agents are taken into account: technical equipment, lights, occupants, sunlight through glass, heat transfer through windows and walls, air infiltration, contact with the ground and ventilation. It is important to note that, to understand the performance of a building in a temperate climate, it is necessary to divide the operation into two typical periods: summer and winter. Some loads, such as sun radiation through the glass, will be beneficial to achieve comfort in winter while they will be inadvisable in summer. The thermal balance of the dwellings depends on all these factors, in a dynamic and variable way throughout the year.

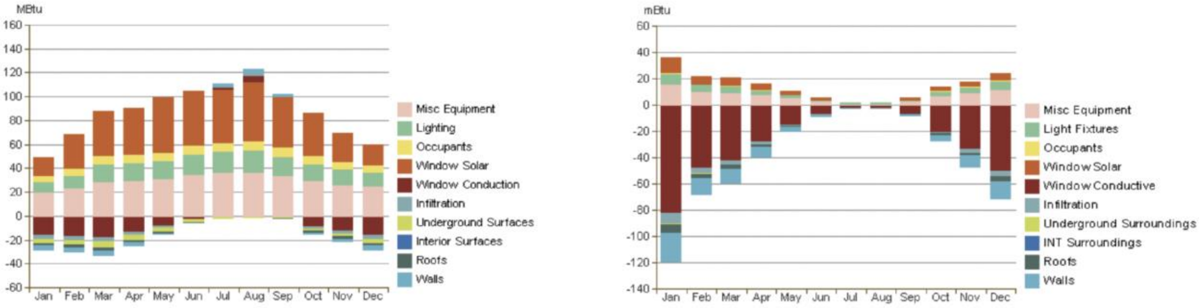


Figure 4. Cooling and heating loads.

https://knowledge.autodesk.com/support/revit/learn-explore/caas/CloudHelp/cloudhelp/2015/ENU/Revit-Analyze/files/GUID-93D60C3D-7424-4B2B-8764-AA277B109174-htm.html

The first and most important strategy for controlling interior thermal well-being is the thermal insulation of the building envelope, in walls, roofs, floors and windows. A large part of the energy is lost or gained through the skin of the building. In summer, for example, in poorly insulated buildings, it will be necessary to incorporate a lot of fresh air into the home to maintain comfort, quickly losing it the moment such contribution stops. Insulation plays an essential role in the performance of the building and in the sensation of comfort / thermal stress. In architecture practice, it is common to use diagrams showing the temperature curve in the width of the walls, which are really visual to understand the performance of the isolation phenomenon and help to place wall layers in the correct order. The curve is steeper for greater variations in temperature per unit of wall thickness, and more tended when the temperature varies less per unit of thickness (Krope, J., & Goricanec, D. 2009). The different layers show different reactions against heat transfer, with the insulation showing the best resistance. The U-value, or thermal conductivity, is the international unit of measurement, inverse of resistance. It is expressed by W / m2K. Thus, the lower the U value of a material, the better its insulating performance. We will return to this issue later, when pointing at the variations in the Spanish Technical Code for Construction (CTE) that appeal to different construction solutions through time.

The next control mechanism for hygrothermal comfort is, undoubtedly, ventilation. As it has been noted above, relative humidity and temperature are two highly interconnected variables. With higher relative humidity values, the maximum comfort temperatures decrease. Also, in hot moments such as Madrid in summer, selective ventilation at certain times of the day allows the introduction of fresher air inside the buildings. The feeling of comfort increases not only due to the introduction of cooler air, but also due to the decrease in the relative humidity of the environment, as the exterior air in dry climates are less loaded with humidity than the interiors. Temperature and relative humidity decrease with the renewal of air at certain times of the day. In Madrid, specifically, night ventilation is a necessary thermal control mechanism during summers, since the temperature drops significantly at night. However, this strategy may result inefficient in the areas with the greatest impact on the Heat Island. In these places the air outside the houses is still hot at night, due to the action of the thermal mass and the density of the building, as explained in the following sections. Ventilation, however, is usually necessary in warm and temperate climates. So much so that there is strong controversy in Spain around implementation of the Passive House standard, that eliminate natural ventilation in favor of technological air recirculation systems (Borrallo Jimenez et al, 2021). In warm climates, we can talk about a “know how” culture for dealing with heat using ventilation, that is mainly expressed in domestic automatic actions, such as closing shutters and blinds to avoid solar overheating. In Chapter 2, on climate adaptation, this issue will be developed. When talking about ventilation, it should be added, that for proper functioning of the strategy, in addition to facing openings in opposite walls, the height of those openings is a determining factor for optimizing the air flow in the room, so that the renovation is as complete as possible. As warmer air tends to accumulate in the upper parts of a room, extraction openings are most likely to be located next to those spaces.

Both the thermal insulation and the ventilation of the buildings have been regulated at a normative level in recent years. The appearance of the CTE (Spanish Technical Code for Construction) in 2006 brought greater demands in both directions, but Spain had regulations on the insulation of buildings - not ventilation - since 1979, with the NBE-CT-79. That delay of Spanish administrations in developing standards for the insulation of buildings is striking. As we will see later, the 1960s and 1970s decades were very prolific in housing construction in cities like Madrid. However, all buildings prior to 1979 were made without minimum insulation requirements, leading to a large number of very inefficient homes in which thermal stress situations are highly probable.

The NBE-CT-79 code was, therefore, the first Spanish regulation regarding insulation. In it, maximum values of thermal conductivity are introduced -the U value, which we saw previously- for roofs, facades and floors. Subsequent to these regulations, there have been repeated updates to these values, becoming more and more restrictive and demanding greater insulation in buildings. Thus, if in 1979 a thermal transmittance U (W / m2K) was required in Madrid of 0.77 for roofs and 1.2 for walls, currently the required value is 0.35 and 0.41 respectively (CTE, 2019), meaning twice and three times more isolation, respectively. Before 1979 these demands were simply non-existent.

The evolution of constructive solutions and thermal insulation in buildings in Spain is a matter of vital importance to understand the object of study of this work: the action of building and urban fabric in the phenomenon of urban thermal stress. The implementation of the first requirements after 1979 explains the reason why some buildings are highly vulnerable to overheating in summer and highly demanding of heat energy in winter in much of Madrid's built stock. To understand the effect of thermal regulations on buildings, it is worth to make a stop at the different construction solutions present in Madrid, in buildings from the early 20th century to the 1980s, with the first insulation requirements put into practice.

At the beginning of the 20th century, the roofs were mainly made of wooden structure -beam or truss type depending on the distance between supports- with ceramic pieces between them, to support the roof tiles. Towards the interior, a false ceiling made of cane and plaster was placed, creating an air chamber that acted as an insulator. This effect is fulfilled by the thermal transmittance of the static air. Even though it is not comparable to conventional insulation nowadays; it does play an important role in this type of housing thanks to its size. All the space between the roofing and the living spaces acts as a thermal buffer, performing warmer temperatures than the interior spaces. Other solutions put into practice in the first decades of the century, and still present in buildings in the urban center of Madrid and the absorbed towns -Madrid´s urban structure is explained later-, is that of lightweight partitions, composed of ceramic walls with cavities. This solution is economical and efficient when it comes to achieving the same effect: the creation of an air chamber that acts as a roofing insulation. Later, with the entry of modern architecture in Spain and the intense use of concrete, many roofs became flat, executed with lightened mortars. The insulation of the old air chamber was performed in these years (1940-1950) by the concrete itself, which, by containing air in its mass, is a greater insulator than that of reinforced concrete. Regarding walls, the development is similar, and it is also significant the shift triggered by the appearance of reinforced concrete. Thus, while at the beginning of the century stone bearing walls or brick walls were still used, later, in the 1940s, reinforced concrete column structures began to be built, where the panels between columns were generally solved with brick.

Another key aspect of this type of constructions is thermal mass. Brick and stone are massive elements - stone to a greater extent - with the ability to accumulate heat. They are not insulating materials, in the sense that their response to the transfer of heat is not enough to thermally insulate a building, but their accumulation capacities, mainly for stone, make them interesting for bioclimatic design. Buildings with stone walls in the center of Madrid have this quality, being cooler spaces in winter, in which the temperatures remain more constant throughout the day. Brick facades complements the high thermal transmittance of its massive clayey part by the lower one in its internal cavities, in which small air pockets are formed. In any case, no building built in Madrid before 1980 has properly insulating materials, beyond solutions based on cameras and increased cladding thickness.

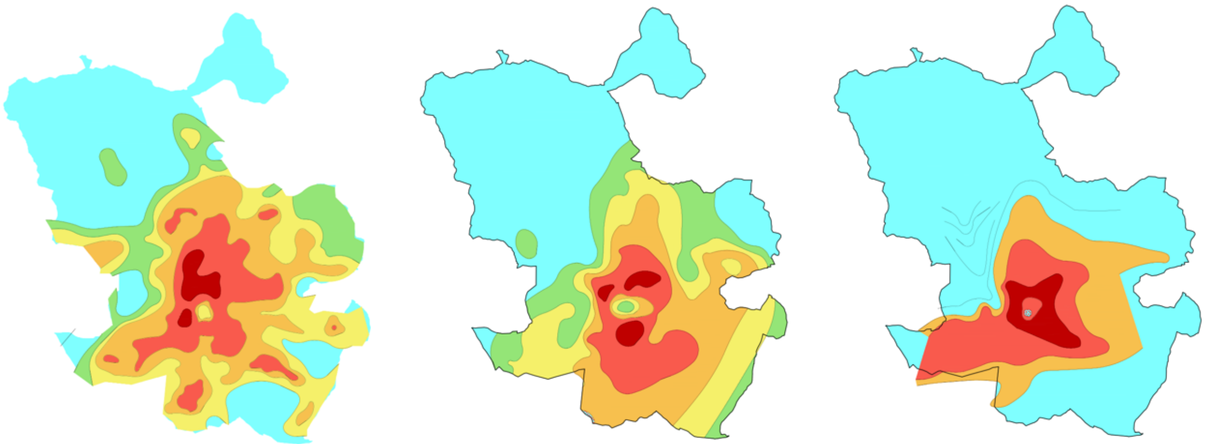
As previously noted, the value of U is expressed in W / m2K, and is the inverse of thermal resistance (U = 1 / R). Thermal resistance is expressed as R = e / λ, where *e* corresponds with the thickness of the wall (or roof) layer and λ is the heat transfer constant of the material in such layer. The lower λ, the better the insulating capacity of the material, resulting in better thermal resistance. Another way to increase the thermal resistance of the enclosure is to increase the thickness. In the case of granite stone, for example, the value of λ is greater than 2, while in insulating materials it is less than 0.1 units. This bad thermal performance is supplemented by very thick walls, generally greater than 50 cm. This brief example explains how some constructions made without insulating material can be habitable -although not efficient- by increasing the thickness of their walls. With the entry of the latest versions of the CTE, these solutions become unviable, and the use of insulating materials in the building, necessary.

1.2 The city's climate

For the characterization of a certain climate, the most determining parameters at an architectural level are dry temperature, wind and relative humidity. As we have seen previously, these factors notably determine the sensation of comfort or heat stress in any environment. Madrid is characterized by having a climate with a lot of thermal oscillation between summer and winter, and the same can be said of relative humidity. The most extreme conditions occur in summer, with a very hot and dry atmosphere. This is due, in part, to its central position in the Iberian Peninsula, as well as to the sun exposure and the low presence of watery masses. The prevailing winds are from south-west origin. The urban topography conditions its local wind regime. As has been pointed out in some studies, the Manzanares river and its channel act as a differentiating element in this regard (Madrid, 2009).

The periods of thermal comfort in Madrid occur in the autumn and spring seasons, although these are not long-lasting. The temperature varies from an average minimum of 2.7ºC in winter to an average maximum of 32.8ºC in summer. Relative humidity drops to 37% in summer, and can reach maximums of 71% in winter (Madrid, 2009).

These data serve to characterize the climatic zone of Madrid (CTE, 2019), but to understand the climatic characteristics of the city it is necessary to highlight some specific aspects, which are related to the UHI effect. The Urban Heat Island of Madrid has been studied by local administrations (Lopez et al, 1993) as well as by the academy (Salamanca et al, 2012), and by mixed collaborations (Madrid, 2009). Some research highlight a great level of detail with enough precision to estimate the UHI dimension and degree of affection by neighborhoods (Fernández et al, 2016). The most recent approaches focus on recognizing the data deficit that allows us to understand the dynamic nature of the process (Nuñez Peiró et al, 2016). Thanks to these contributions we have cartography that allows us to understand the performance of the phenomenon on a large scale (Figure 5). The effect of urban density, natural troughs or green masses is recognizable in all the thematic maps available on the Heat Island outline.



Estudio de Detalle del Clima Urbano de Madrid. (2016)

Madrid Council + UAM

Actualización de la isla de calor urbana de Madrid (2017)

ABIO - UPM

Buenas prácticas en arquitectura y urbanismo. Criterios bioclimáticos y de eficiencia energética (2009)

Madrid Council

🟥 Red: Higher impact on UHI effect

🟧 Orange-Yellow: Medium impact of the UHI effect

🟩 Green: Low impact of the UHI effect

🟦 Blue: Nonexistent impact of the UHI effect

Figure 5. Urban Heat Island maps compared.

Such analysis is perceived as necessary and effective when it comes to arranging and promoting urban rehabilitation plans, and sustainable planning strategies in general, as we will see later. However, in order to characterize the Madrid Heat Island, beyond the distribution of its effect, it is necessary to attend to a smaller scale. The thermal oscillation in the same district, or in the same set of buildings or, even, in the same housing block, can be very high. Heat is not a widespread variable in the territory but rather something sensitive, something that concerns the skin and bodily sensations. Heat responds to the human scale, and is capable of transforming activities, generating customs and protocols. In Madrid the heat has so much identity that it has its own cultural iconography, its rites and its myths. Although it is beyond the objective of this work to enter into the impact of climatic variables on Madrid's culture, regarding the climatic characterization, some popular activities are highlighted here. Protocols and automatic behaviors of people from Madrid may explain, at a generic level, how the city climate changes through the year (Madrid, 2009).

Due to the low average temperatures in winter, in the months from October to March there is a need for solar radiation. Some buildings with more orientation margin in Madrid face south to maximize solar gains in this period (De Luxán and Gómez, 2006). In the winter months, homes usually keep the blinds open and the awnings pulled up all day, opening the windows only at certain times of the day to ensure ventilation. This sometimes generates surface humidity problems, especially in dwellings with worse cross orientation and on ground floors, with more contact with the soil. In the months of April and May there is a sensation of relative comfort, with daily fluctuations in which heating is usually necessary - especially in the morning. From May, June and early July thermal comfort occurs in the mornings, although the afternoons are usually vulnerable moments due to overheating. Windows partly closed at the end of the day are a common feature in the months of July and August, with shutters and awnings protecting from excessive sunlight. This strategy is presented more regularly in the afternoon than in the morning for the reason that in the afternoon the ventilation needs meet the needs for sun protection, making it more difficult to ventilate appropriately. Meanwhile, in the mornings, the contribution of exterior freshness to the house compensates the solar heating. All ventilation strategies are a great ally when it comes to controlling the adverse effects, in terms of thermal stress, produced by the UHI, but sometimes they are not possible. This is because of the high temperature that can be found in the areas outside the buildings, which are being heated up by the energy previously stored in buildings and pavements. Madrid's UHI has evolved since it was first studied (Lopez et al. 1988). Although this increase does not seem to affect the extension of the phenomenon, it does generate increasingly extreme temperatures. This happens at the moments closest to the summer solstice, when there are more hours of solar accumulation (Nuñez Peiró et al, 2017). At a neighborhood scale, microclimates are differentiated, as buildings and the surrounding built or green environment play an important role. To have a mor precise image on Madrid's overheating phenomenon, it is necessary to get close to the built scale, looking at microclimates that are a consequence of the urbanscape, the different building typologies and their climatic performance.

1.3 Madrid's building stock

A brief look at an aerial photography of Madrid summarizes some of the most relevant characteristics of its urban fabric. The city is structured from a dense core -the historic center- where irregular streets and disaggregated porosity in the massive built fabric can be appreciated (Figure 6). Around it, there is an organized city growth - the *Ensanche* - interrupted only by the Retiro park. The next ring in the development is formed by the sum of organized growth, in the 6 exit directions of the city, and centers of spontaneous growth of small settlements occurred along the history. These last correspond to peripheral municipalities that are absorbed by the urban fabric nowadays. The access to the large *Casa de Campo* park is striking, as an intrusion of the natural environment into the city, almost touching the downtown area. The Manzanares River can be seen in a sinuous path along the entire west side of the city, continuing to the southeast.

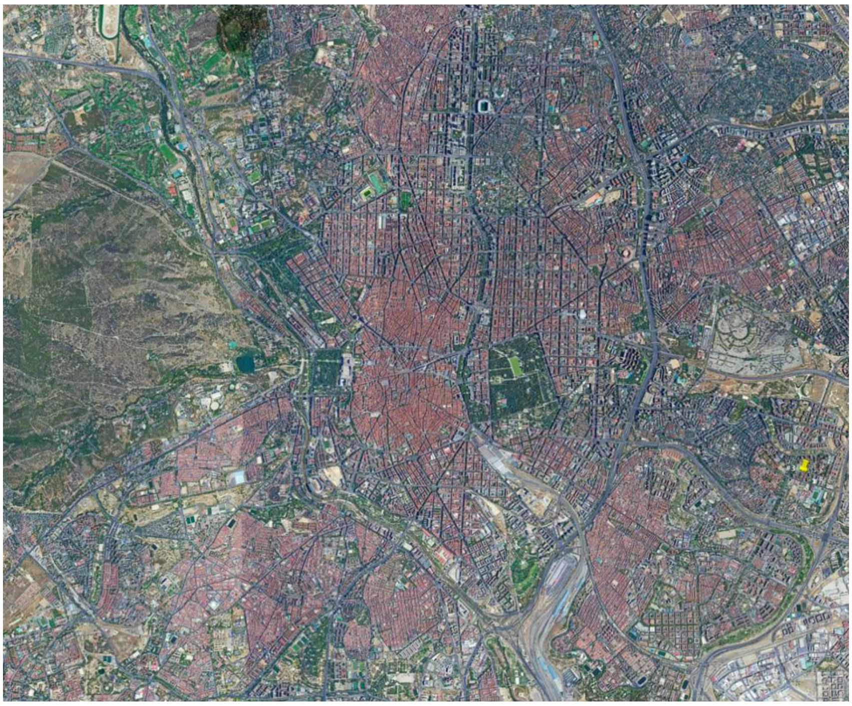


Figure 6. Madrid, aerial photography

Twentieth century urbanism in Madrid

It is not the objective of this work to dwell excessively at the different moments of urban development in the city of Madrid, but it is to expose some basic notions, especially identifying in each era those typologies and main construction solutions, in addition to other aspects that affect the energy performance of the city, such as the orientation of buildings or presence of green areas. Thus, the urban development of the city can be outlined in 4 different moments:

1. Beginning of the 20th century. The city of the early twentieth century is a city of medieval layout and high density, with streets that adapt organically to the orography of the area near the river. The current Retiro Park, the Casa de Campo and the Manzanares River formed the natural limits. A series of access routes led to the main nearby towns (Alcalá, Segovia, Toledo). The lack of sanitation and the problem of overcrowding, characteristic of this type of nucleus in Europe, led to the need to propose a large controlled urbanization project. The second half of the 19th century was dedicated to the development of this plan.
2. 1900-1940. *Ensanche* and housing colonies. The entire execution of the Ensanche dates from the 20th century, in its first third (Barral, 2015). As in many other Spanish cities, the extension of the Ensanche forms the first ring that surrounds the historic center. The transformation of Madrid to become a Great Capital is largely due to this period. The housing construction process is joined by public infrastructure, transportation and services. On an orthogonal mesh, Chamberí and Barrio de Salamanca appear as residential neighborhoods, and manufacturing activity is moved to the south, with railway stations for this purpose. There are also areas in the city of "*hotelitos*", or single-family houses with gardens, designed for the more affluent classes.
3. 1940-1960. Planned tentacular growth. Once the Ensanche has been completed and the projects for single family housing neighborhoods and garden cities have been developed, the need for planned growth arises with the aim of incorporating the peripheral towns into the urban fabric. This translates into a tentacular growth, annexing towns between 1948 and 1954. People arriving in the city without resources have to choose between renting low-quality housing in the center or building informally in the suburbs. Problems of housing shortage start in this period.

4. 1960-1980. *Desarrollismo*. If we look at a graph of the city's demographic growth, the population increase between 1940 and 1980, from 1 to 3.2 million people, is striking (Figure 7). This increase was especially sharp from 1960 on, and led to a great building activity in the city. It is estimated that of the 155 million m2 of residential use built in the city of Madrid, 64.5% are prior to 1980, that is, they lack minimum thermal insulation requirements (Madrid City Council, 2013). Most of the open block housing projects, with landscaped public spaces -*poblados dirigidos*- appeared strongly at the beginning of the 60s, being progressively replaced by projects of private initiative and greater building density. The constructive and typological qualities of this period of time are of great interest for this report, as they are overexposed to urban heat.

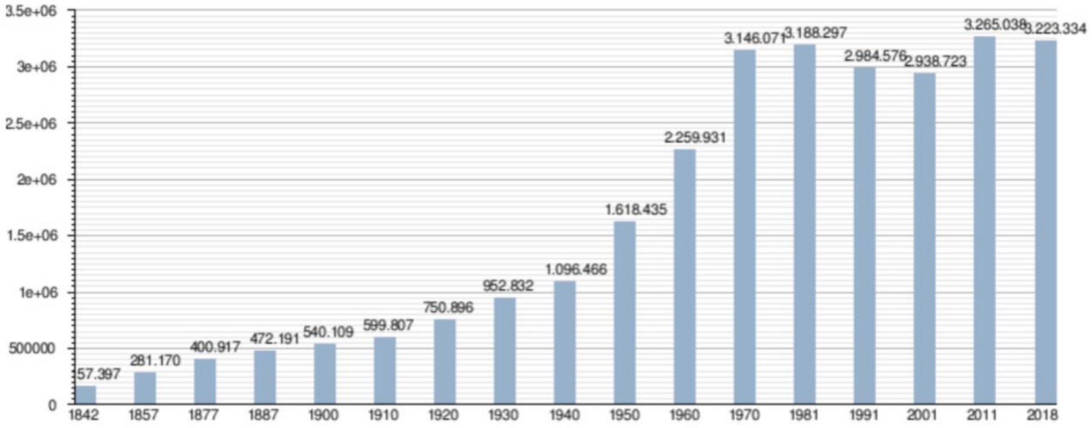


Figure 7. Madrid's demographic growth. INE Instituto Nacional de Estadística

After 1980, with the introduction of the first regulations on thermal insulation, building typologies are considered less vulnerable to overheating. This is also compounded by its location further away from high-density areas and the lesser effect of the heat island. For these reasons, the periods of urban development after 1980 are left out of this report.

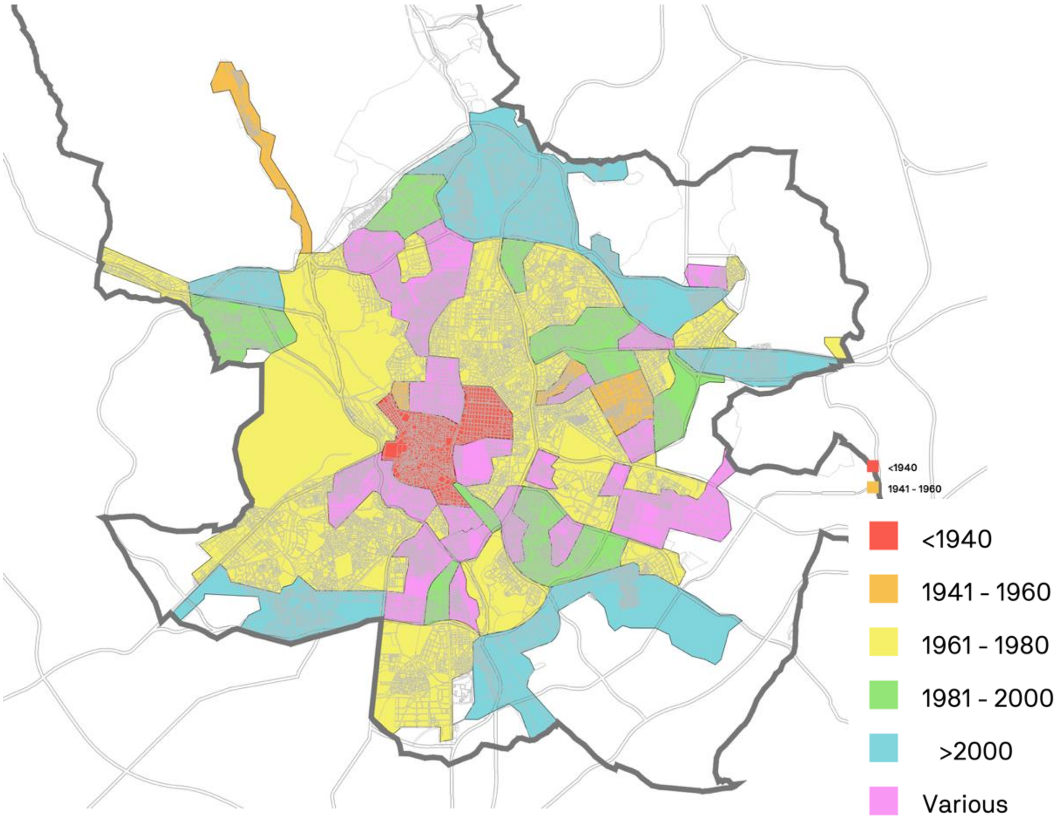


Figure 8. Periods of building construction in Madrid.

Evolution of residential typologies in Madrid and their thermal performance

Historic center and peripheral towns (Pre-1900).

The centers of the peripheral towns prior to their incorporation to Madrid, and the very center of the city, are crossed by narrow streets and deep plots with irregular block courtyards. Rapid urbanization has resulted in many fully occupied lots, where it is difficult to find adequate lighting and ventilation, especially on ground floors. A very common typology in the center of Madrid is the *corralas*, mainly in the Lavapiés neighborhood. The corralas are buildings with an interior patio and access galleries to the houses. These buildings, well preserved, have an adequate bioclimatic function. This is due to the action of the patio, which offers a cool and shady space, and allows cross ventilation at night in summer in all apartments. In addition, they perform usually as green spaces, due to domestic greenery, and where it is also common to see hanging laundry. Both elements refresh the air, creating microclimates in the galleries. The same solution of the galleries offers shading to the openings in the facades. This means that, in the hours of the day of greatest solar radiation, around noon, the windows can be shaded.

However, not all buildings in the historic center have these characteristics. The main problems at the level of thermal stress due to overheating in this area are derived from the difficulty of passively cooling homes -by ventilation- at night, since they are located in an area where the effect of the UHI is more extreme and night temperatures are kept high by the buildings' own heat emission. The buildings in the center are made of massive walls and have a lot of thermal inertia, and density is also higher. This means that all the heat accumulated during the day is returned to the urban atmosphere at night, not being able to adequately ventilate the houses. In addition, downtown areas have narrow roads, resulting in that few streets are shaded by vegetation.

Ensanche and housing colonies (1900 - 1940).

The structure of the Ensanche is formed by a grid of north-south and east-west axes. This means that the houses can have an optimal thermal performance - those that face south, with control of solar radiation through awnings. If we focus on overheating in the warm months, there is the possibility that the dwellings on the upper floors, mainly those facing west, may suffer thermal stress in the last hours of the day due to heat accumulation and excessive sunlight. The section of the street generates completely shaded spaces on the lower floors. This means that there is the possibility in these spaces, and in all those facing north, of suffering more from the winter cold than from the summer warming. The streets of the Ensanche, although of different widths and number of lanes, are generally tree-lined. This offers fairly regular shaded areas on the sidewalks and minimizes the thermal vulnerability of the pedestrian. In any case, this phenomenon is linked to other variables, such as the size of the road and the greater or lesser glazing of the buildings. For example, the Castellana axis is a boulevard widely populated by plant species, but it offers the highest temperature measurements in the summer (Madrid City Council, 2013). In the same way that occurs in the historic center, the Ensanche is made up of closed blocks, with an interior patio that has been occupied to a greater or lesser extent. The absence of public spaces and squares, as a result of speculation and urban congestion of the first half of the century, gives rise to neighborhoods with little presence of concentrated trees. This situation only has the exception of the Retiro Park, which, as can be seen in the cartographies of the UHI, supposes a relief to thermal stress in the surroundings.

The housing colonies are made up of isolated single-family homes, with their own land and trees, which significantly improves the microclimatic performance of their surroundings, unlike the Ensanche area.

Planned growth (1940-1960)

The planned urban growth, after the development of the Ensanche, can be structured in two types. On the one hand, closed-block urbanization projects, generally closer to the perimeter of the extension, where the road layout depends to a great extent on the orography or the adjoining urban structure. The price pressure due to the central location gives rise to a dense urban fabric, where the presence of trees is quite low and where the streets are narrow. In the same way as in the downtown area or in the expansion, the blocks have interior patios for ventilation and lighting of the houses. This part of the city forms a patchwork around existing old towns and does not respond to a clear orientation, but to the need to gradually incorporate specific places to the city.

Figure 9. Poblado Dirigido, Fuencarral.

https://aris.es/project/2008-poblado-dirigido-de-fuencarral/

On the other hand, towards the end of the 1950s, the first planned social housing projects, or *poblados dirigidos*, were carried out, which fulfilled the double function of taking the urbanization process to peripheral towns and absorbing the demand for low-cost housing served with public spaces of a better quality (Esteban-Maluenda, 2000).

These developments were designed by some of the most relevant architects of the time, who showed in their ideation a clear inclination towards the precepts of the Modern Movement. Between 1945 and 1956, concepts of urban experimentation mature, which are fundamental to understand the housing and urban planning projects that will determine the next period of time. At this time, the projects of absorption villages -which welcomed people from homes in poor conditions- and *poblados dirigidos* (PD) -which welcomed people from slums- were forged. The PDs designed so that individual self-construction developers could participate in the execution and save costs to obtain decent housing. The most brilliant example of PD was that of Fuencarral A, in which pedestrian routes were provided to access the houses based on an optimal orientation (Figure 9). Constructive austerity and rationalism prevailed in the architecture of the PDs, and it was the opportunity for Spanish architects to open up to international styles (Sambricio, 2003). This supposes a profuse incorporation of vegetation to the interblock spaces and the prioritization of the pedestrian routes, squares, walks and stairs. Adaptation to the terrain is a constant in these projects, resulting in a certain variety of orientations, where the south orientation prevails when possible. At the level of thermal performance, this carries neighborhoods where the sensation outside the buildings is pleasant, favored by shaded surfaces. However, inside the dwellings the sensation is reversed by the material poverty of the buildings. Thermal stress inside these houses may be higher on the upper floors, due to the lack of insulation of the buildings, although this depends on the building type and orientation, as we will see later. As a conclusion, we can argue that the good principles of bioclimatic design of the PDs and absorption villages, such as the correct orientation, cross ventilation and the presence of green areas (Cervero and Agustín-Hernández, 2018) are counteracted with poor quality of materials and inefficiency of construction in general, motivated by the absence of technical requirements for thermal control and by the primacy of resolving social emergencies in lack of housing.

Social housing (1960 - 1980)

Once the first social housing problems were attended, Madrid continued to receive a large number of new settlers, attracted by the job opportunities. According to the Cadastre -*Spanish Real Cadastre* is an administrative registry where urban and rural real estate is described-, 17% of the buildings of Madrid where built at this time. There is a strong housing construction activity at the beginning of this period to carry out the Social Emergency Plan. In just under 4 years, the I.N.V. (*Instituto Nacional de Vivienda*) build 18,000 homes in PDs and 10,000 absorption homes just in Moratalaz district, for example. Starting in the mid-1960s, the promotion became more from private initiative. This situation led to the construction of a large number of neighborhoods between 1960 and 1979 with similar construction solutions, but with some typological and urban design differences.

In the neighborhoods built by public promoters, linear typologies prevail, in various types, and in heights from 3 to 5 floors. In addition, though to a lesser extent, we find blocks in T and L. The privately-developed neighborhoods, often financed by non-profit religious entities (Fernandez Nieto, 2006), have much higher housing densities due largely to generalized use of the H typology. The different houses in H typology of the private development allow connecting blocks at their corners, in addition to having greater buildability in the plots (Chumillas, 2001), this means, more square meters to be built. This typology is widely used at this time, accounting for almost double the linear ones (Pombo et al, 2014). This leads to the gradual disappearance of the green areas between blocks, being replaced by streets or pedestrian areas of lesser dimension.

For the purposes of thermal performance in these environments, two aspects should be noted. On the one hand, the constructive differences are minimal with what was proposed in the previous stage by the PDs and absorption villages. If we analyze different facades in public and private development homes, we see that the solutions are maintained: brick wall with air chamber and ceramic partition, in addition to thermal bridges (no continuity of insulation) in the slab fronts. The change caused by the increase in urban density does have adverse effects on the sensation of heat and can generate greater situations of thermal stress. This is due to the absence of green areas that, in addition to causing a greater sensation of heat due to direct radiation to people in the streets, causes a greater thermal accumulation in the materials of buildings and pavements, which is returned to the atmosphere at night.

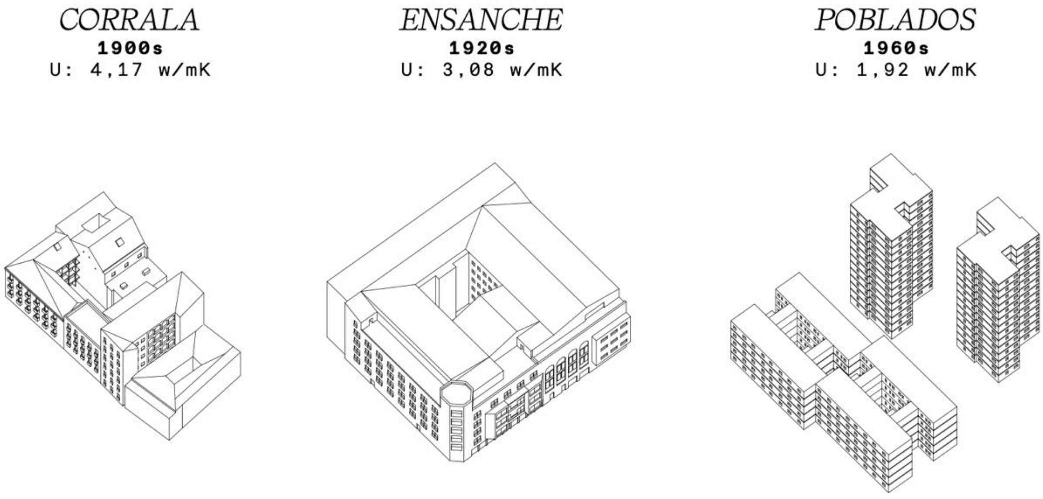


Figure 10. Most relevant XX century building typologies and roofing conductivity.

The differences in terms of the typologies used at this time, and their role in the thermal performance of the homes, are detailed below.

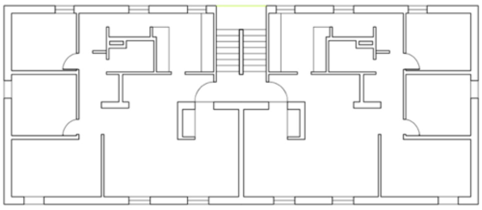
Typologies of social housing - *poblados*: linear, H and tower.

As we have seen, the problem of housing precariousness in the city of Madrid from 1940 to 1980 gave rise to the need to build quickly and cheaply. We have paid attention to how the problem was tackled from different urban planning approaches, and the thermal effect of the different solutions for outdoor spaces. Furthermore, at this time some typologies for residential buildings were introduced for the first time in the city, which had already been previously tested in other European cities. The most prominent typologies are the linear block, the H-block and the residential tower. Much of the city of Madrid prior to insulation regulations is built with these types, so it is worth digging a bit deeper to analyze their thermal performance characteristics.

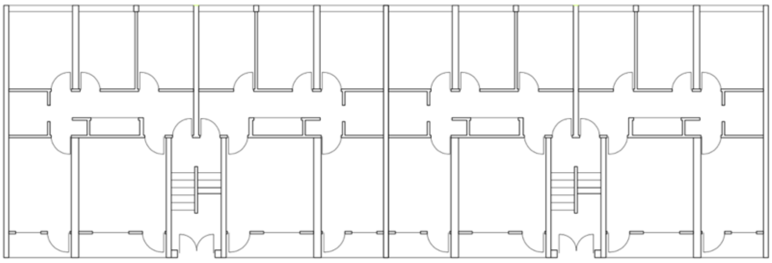
Linear block

As noted, this typology was widely used in public initiative projects, combining it with semi-detached houses with a patio. The linear block is defined by a double bay of concrete pillars and brick walls. The orientation of this typology is usually due to the orography of the area, differing on occasions in that as a matter of the size of the plot the N-S orientation could not be maintained, in favor of the perpendicular E-W. We find a regular intention in facilitating the optimal orientation, in which the most used living spaces turned to the south to leave the wet areas (bathroom and kitchen) to the north.

This situation generates relatively well sunny spaces in winter and easy to protect -with awnings- in summer. The need to use solar protection systems is evident, mainly in those buildings that could not have the most desirable orientation. Another characteristic of these buildings is the good cross ventilation, facilitated by the presence of opposite window openings in opposite walls (Figure 11).



Lourdes *(SW Madrid)*



Fuencarral *(N Madrid)*

Figure 11. Linear block plan.

A strength of this typology is that it is found in open superblocks, in which the reiteration of an orientation, the generosity of the interstitial spaces and the vegetation allow ventilation and the presence of microclimates between the blocks. One problem that linear blocks have is that they generally do not have accessibility through a elevator to the homes, generating situations that can lead to greater heat stress in older people residing on higher floors, due to the increase in their metabolic rate due to the rise through the stairs.

H block

The privately-developed neighborhoods have many homes in H-shaped block, where, by doubling the number of dwelling “served” by the vertical communication hub, higher densities are achieved. The constructive quality of this typology is similar to that previously described -see constructive section- and thermal insulation problems are reproduced due to the poor materiality of the facades and the presence of thermal bridges in the slab fronts.

The greatest strength at the level of thermal performance of these buildings is the presence of the patio, which is a passive mechanism to cool down the houses by ventilation (Figure 12). The patio is a generally shaded space, where the materials do not receive the same solar radiation in the low areas as in the high areas, generating an upward suction of air, which in turn removes the overheated air from the homes.

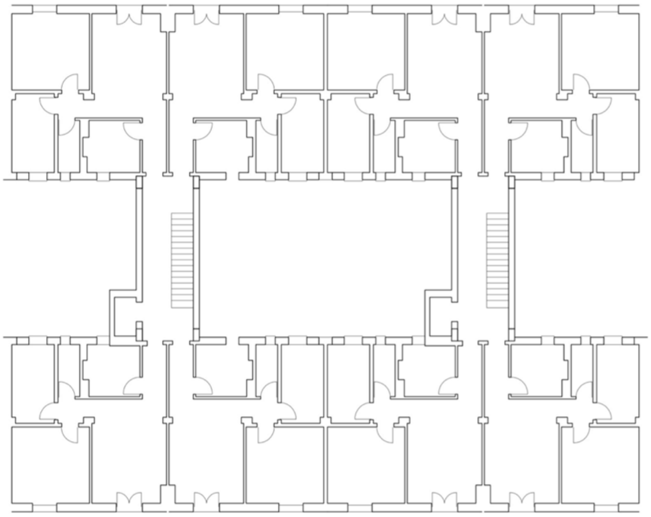


Figure 12. H-shaped block plan.

However, an evident weakness in this typology consists of the lack of vegetation and shading of the exterior spaces, in addition to the impossibility of avoiding the worst orientation in summer, to the west. This is due to the fact that, due to the shape of the H, the houses normally face their spaces of greatest use (living room and main bedrooms) towards the street, leaving the patio for the kitchen, bathroom and secondary bedrooms. For all homes to have winter sunshine, the E-W orientation is usually prioritized, generating overheated homes to the west in summer. As we have explained previously, this is because passive cooling strategies by ventilation are more difficult since the openings must be protected from the sun in the late hours of the day, where fresher air should be incorporated to avoid overheating. In addition, this typology entails the problems of overheating due to urban density that we find in the UHI effect, mainly due to radiation from surfaces and the presence of a greater number of air conditioning systems per m2, which we will explain in the next section.

Tower

Another typology widely used after 1960 is that of the tower. There are a great multitude of solutions, which were implemented in the peripheral neighborhoods in practically the entire urban ring. Some are more similar to the H-shaped block, others are cross-shaped, etc. What the tower typologies share is the presence of a communication vertical core with an elevator in the center, and houses in all orientations (Figure 13). Generally, the houses have two orientations, being placed in the corner of the tower and having 4 dwellings per floor.

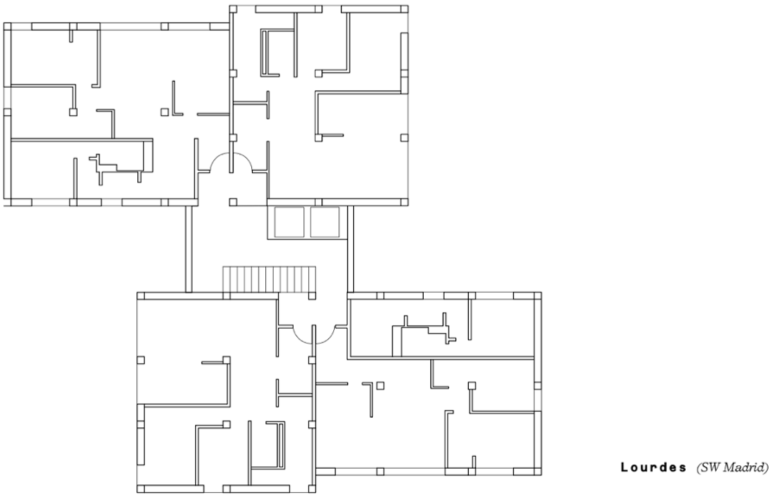


Figure 13. Tower plan.

A point in favor of the tower-type solution is that, as it is a point element and not longitudinal one, its orientation can be chosen. We generally find in Madrid towers oriented according to the N-S and E-W axes in the cases of housing developments in open blocks, where green areas absorb the difference of angles with the street. An example of this can be found in the towers of the Batán neighborhood or in Comandante Fortea street. In areas with less presence of green areas, where the road layout barely leaves spaces to damp the turning of towers, they tend to orient themselves according to the directions of the streets, which in turn are governed by the urban superstructure. This is the case of the towers in the Begoña neighborhood.

Another favorable point for the tower solution is the presence of an elevator. This, as previously mentioned, is a fundamental issue and concerns the sensation of thermal stress in hot Madrid summers. As noted at the beginning of this report, thermal comfort is also influenced by the type of activity carried out. For people who are vulnerable to heat, maybe overweight or elderly, the activity of climbing stairs can suppose an overexertion, determining in a situation of thermal stress that they might not experience without that “extra” effort.

The most vulnerable aspects of the tower are the bad cross ventilation that they present, since we rarely find facing facades in this solution. In the same way, on the upper floors, you can experience a greater sensation of thermal stress due to the accumulation of heat in the building itself and due to the absence of trees that cast shade on the windows.

As we have explained before, in Madrid there are a large number of buildings built before the regulations on thermal insulation, which, however, can be framed according to some common building systems and building typologies. The need to build a lot and at low cost meant that all the experimentation, which had been sought in the first years of social housing, was making way for repetition. What we find in Madrid, in the peripheries that border the M · 30 highway, is that many neighborhoods look similar to each other, where the linear blocks, H-blocks, and towers, are repeated. We find a difference in terms of circulation spaces between buildings, the separation between them, or the presence -or not- of greenery. But where the solutions are most similar is in the construction aspect, with the exposed brick finish and the reinforced concrete slabs peeking out of the façade. Some buildings have introduced retrofits, such as changing windows or closing terraces -the adaptation possibilities for this type of building are detailed in the second chapter-, but what is common to them is the high degree of vulnerability to the heat stress. So much so that we find this type of building as an object of study in a good number of works when it comes to energy inefficiency and vulnerability to climate change (Figure 14) (Cuerda et al, 2014; Córdoba-Hernández et al, 2020; Pombo et al, 2014; Sánchez et al 2017). A good way to identify vulnerable homes is to look at their year of construction, something that can be found on online portals (Hernández et al, 2019). But, in addition to the age of the building, which indicates whether the developmental stage prior to NB CT 79 was built, another determining factor is the dynamic and multiscale performance of the UHI itself. We will dedicate the following pages to understand its correspondence with the road, green and built structure of the city.

Figure 14. Avila, Madrid and Seville linear blocks.
(Sanchez et al, 2017)

1.4 Overheated dwellings.

If we return to the thermal maps (Figure 15), we see the influence of some green elements -Retiro park, Casa de Campo and Madrid-Río park- when modifying the isothermal lines. On the three most noteworthy cartographies (Madrid City Council, 2016; ABIO, 2017, Madrid City Council, 2009), in which the methodology of data collection has been detailed, we find a series of invariables, which are useful to point out the most relevant factors for increasing or tempering heat in the city.

On the one hand, the action of the arboreal mass as an attenuator of the effect of the UHI is irrefutable. As we can see in all the thermal cartographies presented, and also in those from more than 30 years ago (López Gómez et al, 1988), the Retiro Park acts as a thermal buffer of freshness in the urban center where, otherwise and according to the extension of the warmer areas, temperatures could be higher than those recorded today. The Retiro Park has a big number of large trees, and also has assisted irrigation and a large pond in the center. The simultaneous presence of green and blue infrastructure is one of the most effective measures when it comes to controlling urban overheating. We will return to this point later.

Another invariable that we find in all the thermal maps of Madrid is the action of the Casa de Campo, which, as a large non-built mass, acts like a non-urban area, maintaining the regional climatic values closer to the urban center throughout the west side of the city. The Parque del Oeste, as an extension of the Casa de Campo beyond the Manzanares River, further prolongs this effect.

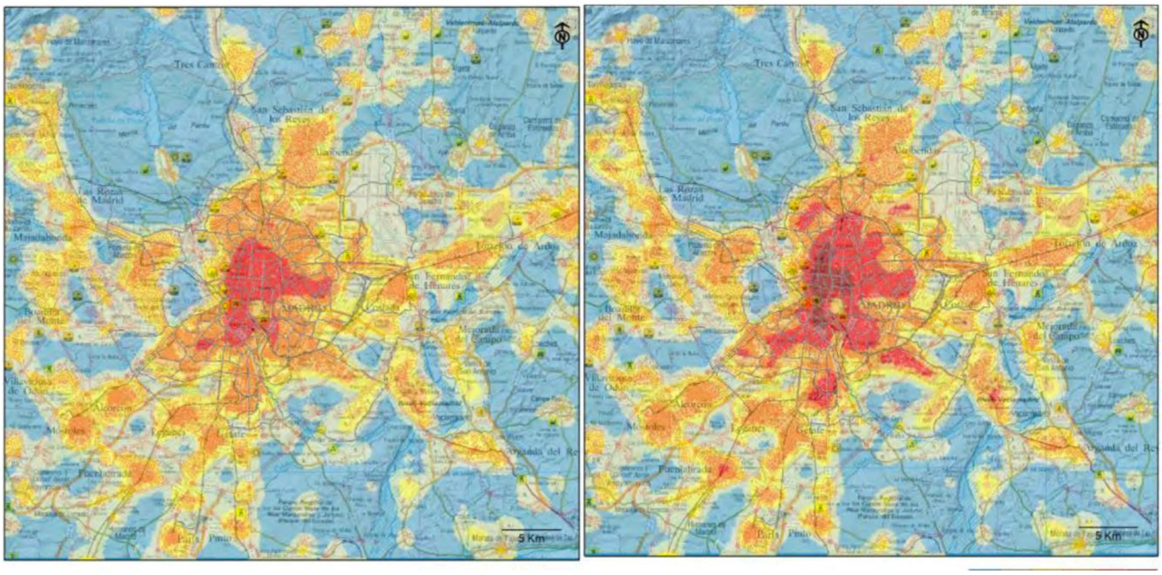


Figure 15. Madrid thermal map, UHI: average summer distribution (left), overheated days (right) (Madrid, 2016).

Other insights are the greater extension of the thermal island towards the south with respect to the north, where, in addition, the most unfavorable conditions of habitability exist. This may be due to the different building typologies that we find at both ends, being single-family house with a garden more common in the north.

It is also important to note, based on the observation of the thermal maps of Madrid, that the action of the river is obvious, as it integrates cooler air from the Casa de Campo towards urban areas, limiting the extension of the UHI on the flank southeast. The UHI effect also has a lot to do with building density. We will see later how the correspondence between the climate map and that of the different building densities is clearly identifiable.

Finally, it is interesting to note that in all the UHI maps there is a correspondence between building density, a greater number of inefficient buildings, and higher levels of thermal stress (Figure 19).

The effect of urban greenery on the overheating of Madrid.

As has been pointed out, the action of urban greenery to minimize the effects of urban overheating is clear. However, this action depends on some variables, since not everything considered as a green area acts in the same way. As we will see in the chapter dedicated to adaptation measures, the joint action of green areas and blue infrastructure can lead to considerable drops in temperature, and this is something that is being explored by the Madrid City Council, as we will see in the chapter dedicated to policies. Now, returning to thermal mapping, a series of larger green areas in the city have been highlighted, each with maintenance systems and different types of flora.

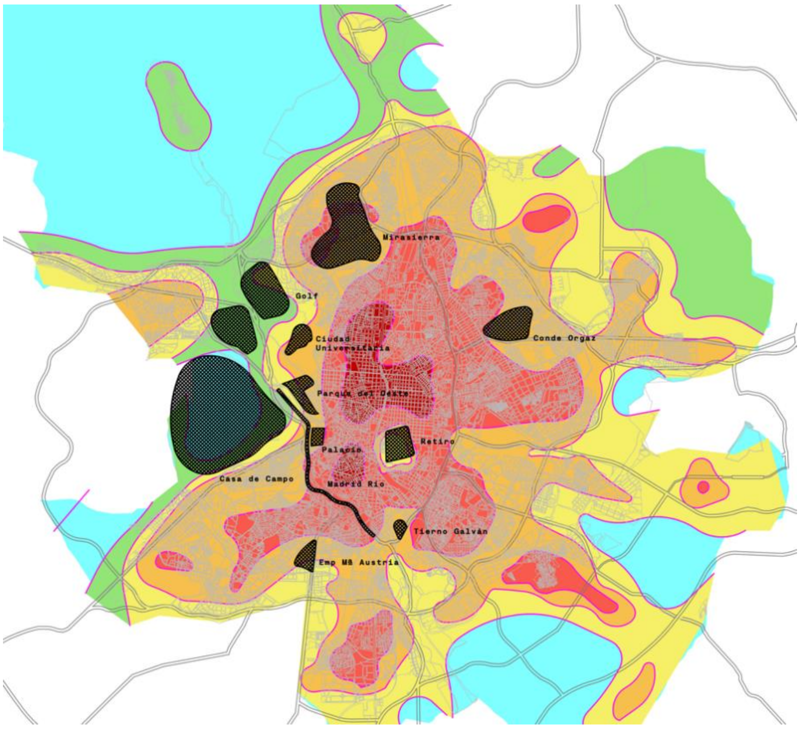


Figure 16

▨ Main green areas interrelated with Madrid thermal map. Own elaboration

To the north we find the area of single-family homes of La Moraleja, Conde Orgaz and Mirasierra. Especially interesting is the Conde Orgaz neighborhood, with its marvelous pine trees on the public road and with extensive gardens for neighborhood communities and single-family homes. In these neighborhoods there is the highest ratio of swimming pools per inhabitant. The action of all these elements produces an evident effect on the heat island contour, whose temperature values differ markedly from the neighboring places (Barrio del Pilar or Las Tablas).

A similar situation is found in other urban parks, where the pine species - endemic to the area - are present. This happens in areas such as Ciudad Universitaria, El Pardo, Parque del Oeste or Casa de Campo. The large size of the species in that area, where on the other hand there is no need for irrigation, and the proximity between them, produces a cooler ecosystem throughout the west side of the city. Ideally this could be introduced towards the most vulnerable neighborhoods in the south, by the action of the river. Some of the municipal proposals to adapt to Climate Change use the river as an argument and vertebral axis of fresh air and ecological corridors.

Other more domesticated parks, such as the Madrid-Río linear park, the Tierno Galván park, or the Emperatriz Mª de Austria park generate cooler conditions, also due to the presence of fountains and night-time irrigation systems. It is interesting to note that other peri-urban areas have high heat values, due in part to urbanization processes in which the tree mass disappears and asphalt areas appear, remaining undeveloped for years.

The effect of building typologies on overheating in Madrid.

Some considerations about the building typologies have already been highlighted, mainly in terms of their thermal performance, when offering interior comfort. But, returning to the thermal map, could any correspondence be argued between urban typologies and the extent of the UHI?

As indicated in the previous part of the report, some typologies are more suitable when it comes to offering comfort conditions, at the building and neighborhood level, such as -obviously- single-family homes with gardens and pools, or apartment blocks located in open block areas with trees between buildings. In the following plan, a distribution analysis of the typologies in the city is observed, using a 200x200m grid, and indicating with a color the type of majority building in the corresponding sector. This work was started by the ABIO research group, from Polytechnical University of Madrid -UPM-, and here it is complemented and continued (Figure 17).

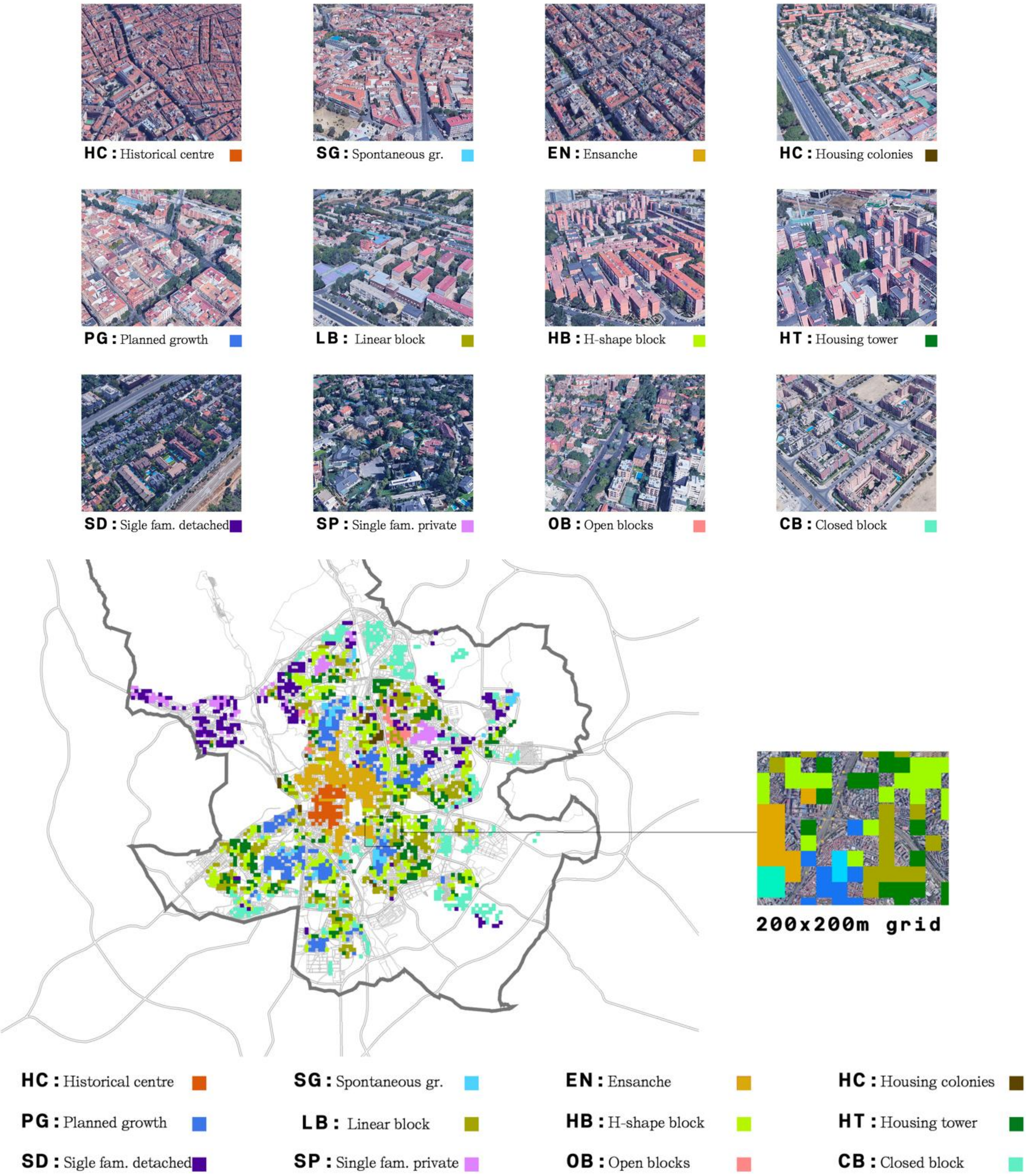


Figure 17. Building typologies distribution in Madrid. Own elaboration

A first observation is the presence of more homes with a private garden in the north of the city; either by isolated house or semi-detached house, or by the more modern types of open block in closed block or closed block with central garden. The chance of having a garden near the house, with the addition of a private management for it, which ensures irrigation and maintenance, promotes a microclimatic performance of the space. The same can be said of the housing colonies of "*hotelitos*" built at the beginning of the century, in which the internal tree mass generates oasis-like situations in places quite close to the areas of greatest thermal stress.

Another relevant correspondence between the heat map and the typological map is the extension through "tentacles" of the city by planned, closed-block, high-density growth. This typology, the majority until 1950, generates situations of high thermal stress, as can be seen by the greater prolongation of the UHI where these types of settlement are greater, towards the southwest of the city.

We also see how the ring of buildings built between 1940 and 1980 is clear -the ones colored in green-, its correspondence with urban heat being less evident. Some of these buildings, mainly those with higher density -to the southwest of the city, in typology H- present situations of high thermal stress. A clear example is that of the Aluche neighborhood, where the temperature records rise significantly.

The effect of the river on the overheating of Madrid.

It would be more precise to talk about the rivers, since Madrid has two main wind corridors, generated by the Manzanares and Abroñigal rivers. Both have been decisive in urban morphology, although in different ways. While the Manzanares River has been restored, channeled and equipped with new green areas for promenades on its sides, the Abroñigal River lies under what is now the M-30, the highway that bypasses Madrid and that on its east side buries the old river bed. The action of riverine channels in the mesoclimatic functioning of the city has been studied (Fernández García et al, 1996), and the most relevant issues for the objective of this work have to be noted here. Due to their orographic depressed condition, cold airs tend to accumulate. This situation can be harmful in winter, causing situations of intense cold, but favorable for the same reason in summer.

In the compilation of data carried out in 1993, the importance of urban topography is pointed out - in addition to other factors mentioned here, such as variety of land uses, or urban density - as a determining factor of the UHI. In this regard, there are differences between the Manzanares river, where the temperature drops can reach 8-10º, and the Abroñigal river, with differences regarding the temperature peaks of approximately -3º.

This is due, to a great extent, to the great differences in the urban landscape in both spaces. While in the case of Manzanares the presence of trees is generalized, with large attached parks -Casa de Campo, el Pardo, Madrid Río-, the Abroñigal channel is located in a purely urban area and widely paved. The lowest temperature values in the Abroñigal trajectory are located at its meeting with the Manzanares (Idem, 1996).

The longitudinal profile of both cannels, their topographic differences, also play an important role in the different action they exert on urban heat. While in the Manzanares the valley begins at a certain distance from the city, allowing for more distant fresh air to be introduced, the Abroñigal generates its depressed relief already within the municipality, acting as a barrier to the penetration of that air. In any case, these values are not static. The extent and location of the maximum temperature values change throughout the day in both troughs, and in different ways. While in the warmest hours the most overheated places are on the northern periphery of the Manzanares valley, this happens in the south of Abroñigal. At night and in the early morning this situation is reversed, moving the maximum values to the south of the Manzanares and those of the Abroñigal in all its route except to the south.

The effect of urban density on overheating in Madrid.

One of the major factors in increasing the UHI effect is building density. However, it should be noted that this situation occurs in the current conditions of construction systems and energy performance of buildings.

When we want to look at the building density -not housing density, but rather volume of built environment- we need to pay attention to compacity. Compacity is expressed by the surface of livable space that can be built in every unit of surface of land (m2/m2), by adding floors and suppressing open spaces. As can be seen in the superposition of compacity with the thermal map, the highest values of thermal stress are occurring in the city where the urban density -or compacity- is higher (Figure 18). This happens for a number of reasons.

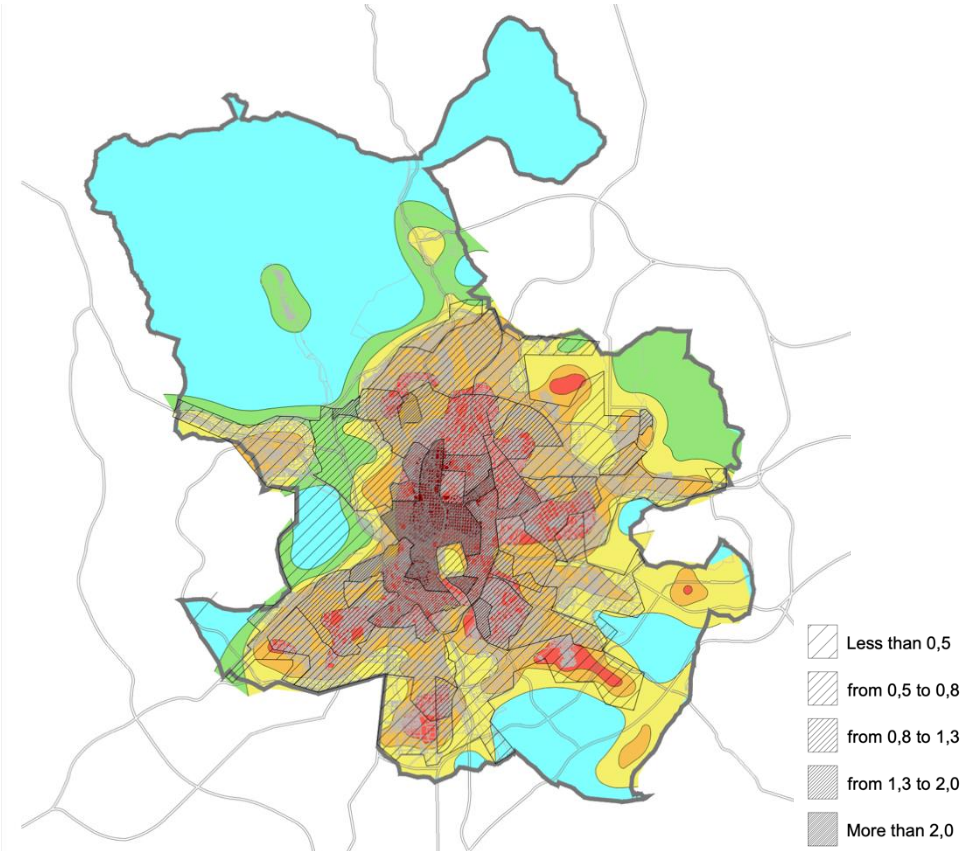


Figure 18. Different compacities (m2/m2) interrelated with Madrid thermal map. Own elaboration

On the one hand, the higher density of buildings leaves less space for vegetation that tempers the microclimate conditions in the public space, due to the mechanisms of solar radiation obstruction and evapotranspiration, which will be explained later. On the other hand, the same density usually occurs in old housing environments, in the historic centers of the city and its peripheral centers. These buildings are usually of massive construction -such as solid brick or stone-, which are materials with high thermal inertia. This means that the heat that they accumulate during the warmest hours of the day is returned to the atmosphere at night, when the house could be ventilated and incorporate fresh air. The nocturnal atmosphere in places in the center of Madrid maintains high temperature values as a result of this phenomenon.

Furthermore, the same buildings in these areas tend to be energy inefficient, requiring air conditioning devices to maintain indoor comfort conditions. Buildings requiring AC return heat to the atmosphere on the roofs of buildings. The heat island moves above the rooftops, avoiding proper ventilation of the air masses in the streets at the ground level.

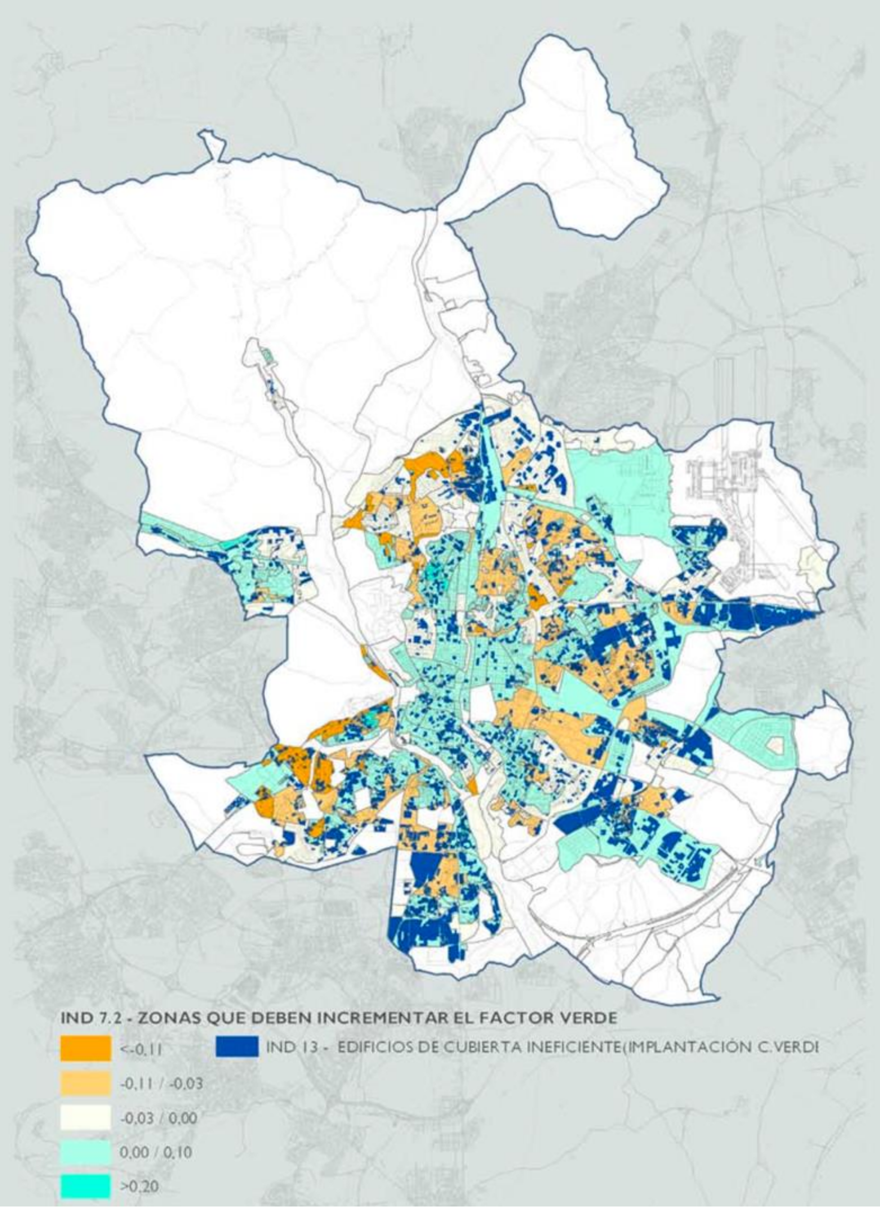


Figure 19. Inefficient buildings and green factor incrementation need.
Orange: Lower incrementation needs
Green: Higher incrementation needs
(green area m2/ urbanized area m2)
Blue: Inefficient buildings

Review on the General Plan. Madrid Council, 2013

Above, we can observe a mapping of inefficient roofs, developed by the Madrid City Council in 2013 on the occasion of its review of the 1997 Municipal General Plan in environmental matters (Figure 19). It proposes to expand the green factor, meaning areas that should increase their number of green areas, in those places where there is a greater number of inefficient buildings -marked in blue. These buildings add more heat to the atmosphere as a result of the AC appliances that cool down the interior. The phenomenon also increases notably in peri-urban industrial zones. This measure reflects the needs to control the effects of Climate Change, mitigating the values of urban thermal stress by verifying the streets, and it is - as can be appreciated - clearly related to the known values of the UHI. Together with other actions promoted by the City Council, in the field of energy efficiency and rehabilitation, they form a set of measures and plans that are specified in the last chapter of this report.

The effect of inefficient dwellings on internal overheating in Madrid.

In the previous section we have pointed out the effects of building density on urban overheating, taking into account the available cartographies. One of them is the greater need for active cooling systems, which entail an increase in temperatures outside the building.

But undoubtedly the most direct effect of energy inefficiency is the lack of comfort inside the buildings, which can produce high thermal stress effects on residents. The income level in many cases determines the possibility of installing cooling equipment, the central areas generally being more prone to this option, due to their higher income level. Thus, although we can identify high temperature values in the urban center and on the sides of Paseo de la Castellana, this does not always result in situations of thermal stress inside the houses. To find these situations, it would be interesting to attend to the thermal vulnerability of the different neighborhoods of the city, which is determined by their income level, the building type, the year of construction and the degree of improvement of the building (Sanchez et al, 2017). As we have seen previously, the high-density H-blocks, built in the 1960s and in more impoverished areas of the city, are places with a high degree of vulnerability to climate change, generating situations of thermal stress that are aggravated in aging population and in higher flats. The inefficiency of these buildings is determined by the low material quality of their facades without insulation, the solutions with numerous thermal bridges, the poor carpentry and glazing, and the difficulty to ventilate correctly, as main factors.

As can be identified in the different categories that have been presented above - presence of green areas, watery masses, typological differences, urban density and energy inefficiency- affect the sensation of comfort or thermal stress in the city. At the microclimatic level, these situations can be interrelated with others, in their relation to the architectural scale and user scale. Thus, the urban climate occurs as a multiple and trans-scalar phenomenon. The measurements that have been presented at the beginning of this section, transferred to academic and municipal knowledge through urban thermal cartographies, being of great documentary validity, do not seem to address the enormous diversity of issues related to thermal stress in the city. To get closer to the experiential and situated heat stress of urban dwellers, it is interesting to specify the different climate adaptation strategies that can happen -for the city of Madrid- at the different scales of adaptation.

Chapter 2.

Urban and architectural adaptation to thermal stress in Madrid.

In this chapter an analysis of the strategies that, at different scales, can be implemented to reduce the thermal stress generated by the UHI of Madrid is carried out. The aim of the chapter is to answer the question of what can be done to combat heat stress in the city. The chapter proposes and delves into a series of measures that would be appliable to the city, relying on practical examples or technical analyzes that have been carried out within its context. Thus, the chapter serves as a joint between the previous one - in which we saw the starting situation, definitions of comfort and thermal stress and thermal performance of the Madrid’s building stock and planning, and the next - in which the measures promoted by the administrations are analysed. In this section, climate adaptation strategies are detailed and evaluated, and their implementation in public policies is evaluated. The chapter is divided into three scales: urban, in which city-level strategies are grouped, and which are determined by urban regulations (ordinances, partial plans, improvement plans ...); architectural, in which the most appropriate building-level strategies for Madrid are collected, and which is determined by the architectural design; and of the user, in which those strategies of use of the city and buildings can be implemented from the capacity of action of the people. With this, the aim is to attend once again to the multiplicity of the urban thermal stress phenomenon, from an approach centered on the building and its multiple scales of relationship.

2.1 Urban scale

When analyzing adaptation strategies at the urban level, two groups must be differentiated, defined by the object of intervention. On the one hand, we find strategies that are aimed at modifying the intrinsic conditions of the built stock, affecting the interior spaces more directly. That is, the orientation of the urban fabric, the distances between buildings and the generated solar obstruction angle, the existence of open or closed block buildings with a patio, the building density, the current construction systems and the presence of flat roofs. They are detailed later. On the other hand, we find strategies that are aimed at modifying the exterior conditions, and affect open spaces more directly. These are the presence of deciduous green areas to control solar irradiance or perennial trees to protect against the wind, the existence of blue infrastructure (rivers, fountains, ponds ...), the orography of the place, the permeability of the soils or the finishes of the facades, roofs and pavements.

Intrinsic characteristics.

2.1.1 Orientation of the urban fabric.

An important part of the city of Madrid is conformed by the Ensanche district, which is defined by an isotropic orthogonal mesh with NS and EW orientation. In the mid-twentieth century developments, which grew towards the peripheral municipalities and in the 6 main directions out of the city, the urban plots are determined by such orientations. In the buildings of the PDs, however, we find a predominance of the buildings oriented with their main facade to the south (Martín-Consuegra et al, 2018), improving their energy performance compared to the previous social housing projects. Even so, in the buildings built between 1950 and 1980 we see how the criteria is very diverse, prioritizing decisions of adaptation to the terrain or geometric seriation, or the use of available spaces. In the latter case, there are strategies in which the facades are adapted to “look” towards the south, where climate control at different times of the year is easier. With regard to future urban developments, the predominance of the south orientation and, above all, the denial of the north-west (which only receives solar input at the times of the year and the days of the year when it is least necessary to heat) should be favored. However, we do not see that this strategy is repeated, prevailing in developments after 2000 large closed blocks that make it difficult to implement a well-oriented façade in many cases (de Lucio, 2017).

2.1.2 Distance between buildings.

The distance is not a value in itself, but the solar obstruction angle is, which takes into account not only that distance, but the orientation determined by two nearby buildings. Although this factor is more related to climate control in winter, by determining the shadows thrown that hinder thermal gains from solar energy in homes, it can also be decisive when it comes to controlling urban heat stress. However, it can be a difficult matter to handle. Contrary to the desirable effect in winter, of maximizing sunny areas, in summer it is necessary to create urban porosities -such as patios- cool and shadowed, which also serve to cool homes by cross ventilation. This can be achieved by combining the distance with the placement of the buildings in the least required orientations in winter. However, generally there are no ordinances that detail any requirement in this regard, being normative more directed towards the control of the volume inside of the plot and not towards the surrounding preexistences.

2.1.3 Existence of open or closed blocks with a patio.

The city of Madrid, as we explained in chapter 1, shows a very varied set of block typologies, alternating very dense areas with small patios -in the center-, semi-dense closed-block areas with a large patio -in the widening area or the PAUS -, public open block areas -in the PDs- and private open block areas -in developments from 1990 onwards. This diversity makes a homogenizing urban proposal unfeasible. The areas where the density is higher and the effect of the UHI is higher, can nevertheless be provided with regulatory ordinances that facilitate the opening of facades and patios to favor cross ventilation of homes (de Luxan et al, 2008). At the urban level, it is essential to ensure air circulation, generating cool corridors. This situation is easier in open block areas, especially if the interblock spaces are correctly greened.

2.1.4 Building density.

The effect of building density on urban overheating has already been discussed previously. In order to not repeat the arguments, and in line with the search for adaptation strategies pursued in this chapter, it should be noted that density can also provide better “clothing” for buildings, as it is understood as urban compactness. This means that the surfaces in contact with the outside are minimized, making it easier to keep homes at comfortable temperatures. For places where the density is high, the search for compactness through, for example, the suppression of traffic in determined streets, can be bioclimatically advantageous. If the heat exchange is established with outdoor areas that maintain the freshness of the house, greater compactness can be generated, without the need to decrease the density. Understanding the street as an extension of the house, which serves as a thermal buffer instead of a radiator, maintaining the internal thermal conditions, can be an argument for implementing climate adaptation measures. The appropriate density must find a balance, establishing climatic buffer zones between blocks and alternating different building typologies (Mueller et al, 2020).

2.1.5 Age of the buildings and degree of updating.

Regarding the influence of the age of the building in terms of energy insulation, the most relevant aspect has already been pointed out: all buildings built in Spain - therefore, in Madrid - that date before 1979 did not have to meet insulation requirements, beyond of those determined by the architects at the time. Today, in the city of Madrid, many of the energy renovation improvements of buildings focus exclusively on addressing this deficiency, with what is called an ETICS (Varela et al, 2018), or external insulation, which is simpler to integrate into existing buildings. These solutions significantly improve the performance of buildings, and must be promoted in order to reduce thermal stress in homes. A variable therefore is the degree of updating of the urban built stock to the criteria set by the current CTE. As we will see in the chapter dedicated to urban policies, Madrid has allocated aids to the renovation of buildings, however, in many cases, promoters find it more important to pay attention to accessibility rather than to thermal insulation. This can help in reducing heat stress situations in vulnerable populations forced to climb stairs of up to 5 floors, but it does not solve the situations inside the houses. In addition, the City Council does not have a complete knowledge of the state of the homes, as the latest methodology for calculating the thermal and energy performance of the homes is not integrated into the official verification protocols.

2.1.6 Presence of horizontal roofs.

Horizontal roofs can be an effective argument when adapting to urban heat stress situations. With the implementation of green roofs or with the simple placement of insulation, the performance of buildings can be significantly improved. In addition, flat roofs allow a correct placement of photovoltaic panels, oriented to the south and with optimal inclinations, facilitating the incorporation of cleaner electrical energy in buildings. In Madrid, many inefficient buildings have gabled roofs, insulated with an air chamber, which makes the implementation of these strategies quite problematic.

Extrinsic characteristics.

2.1.7 Presence of green areas.

We have seen at different times the importance of green areas as a thermal buffer when correctly inserted into the urban fabric, facilitating areas that are protected from solar radiation on facades and streets. The tempering effect generated by the tree mass is a two-way phenomenon: on the one hand, in summer, the shadow reduces the heating energy that reaches urban surfaces, on the other hand, in winter, that same shadow can be detrimental to the objectives of heating up the spaces. On many occasions, this double circumstance is solved with deciduous trees, which in winter allow the sun's rays to pass through due to the loss of leaves and in summer they properly cover the streets and buildings. The different types of trees give rise to shades of different quality, notably influencing not only the size of the leaves, but also their growth pattern or their inclination (Badarnah & Knaack, 2008).

Without a doubt, the phenomenon of passive cooling through trees has a lot to do with the phenomenon of evapotranspiration. The moisture accumulated in the leaves of the trees tends to evaporate, due to high temperatures and solar radiation. This evaporation needs to capture energy from the environment, diminishing temperatures. The sum of this phenomenon, on a small scale, in the foliage of thousands of trees, can produce significant effects on urban temperature, as evidenced by the temperature data of the Retiro Park in relation to its surroundings (Figure 20). Some studies maintain that such an effect can be between 2 and 8 degrees of cooling (Shishegar, 2015).

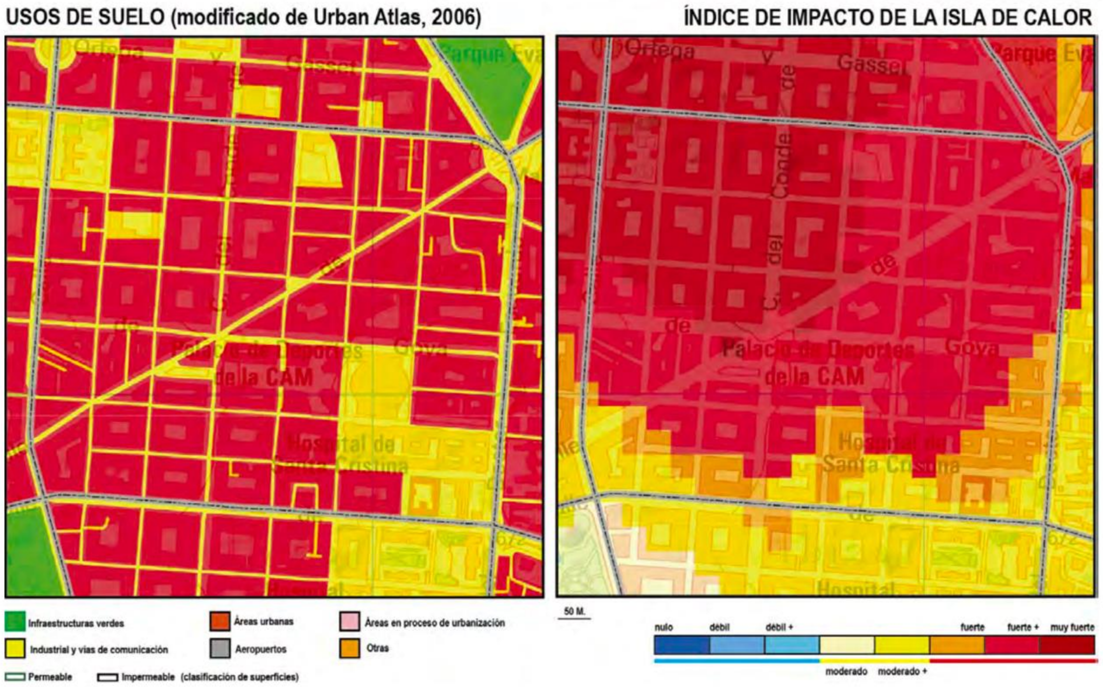


Figure 20. The thermal effect of Retiro Park -bottom left corner- in Goya District (Madrid, 2016)

For a better use of evapotranspiration cooling, the air must be circulated, since an excessive increase in relative humidity values may not be comfortable, as was explained in chapter 1. In any case, in cities like Madrid, with a very dry climate in summer, the risk of discomfort due to humidity saturation is practically non-existent.

The moving air, passing through the leaves, decreases its temperature and carries cooler particles to the surrounding places. For this reason, urban greening measures can be more effective if they are combined with wind corridors, which allow fresh air from the periphery to penetrate into the interior of the city. Urban green must also be associated with irrigation and maintenance measures, preferably with reused water -for the energy cost involved-, so that the operation of the entire tree-evapotranspiration-ventilation mechanism works correctly. In Madrid, urban greening initiatives have been launched in recent years, directly connected to the needs of climate adaptation. They are detailed in the next chapter.

2.1.8 Presence of blue infrastructure.

The thermal performance of blue infrastructure can be notably different from that of green areas, depending on the type of infrastructure. Thus, in coastal cities, the sea has a tempering effect on both summer and winter conditions. The thermal mass of large aqueous bodies exerts an inertial action, minimizing highly marked temperature peaks. However, taking into account the risks of thermal stress, we can find situations where despite having lower temperatures than cities like Madrid, some coastal places are less comfortable due to high humidity. In Madrid, the blue infrastructure is inserted discontinuously: the Manzanares River is the largest water body, and its effects on the heat island have already been detailed previously. In addition, many squares in Madrid have a fountain, which produces the same evapotranspiration effect of urban trees. Other possible bioclimatic strategies using water are the selective irrigation of public areas and gardens, the installation of vaporizers on public roads or increasing the number of fountains in streets and squares. The sum of multiple small-scale interventions that take into account -as we explained in the previous section- the prevailing wind patterns can produce a very advantageous effect to mitigate urban thermal stress (Gunawardena, Wells & Kershawa, 2017). This is highly recommended in a city like Madrid, with a dry climate that eliminates the risks of discomfort due to relative humidity and is far from the inertial effect of watery maritime masses.

2.1.9 Orography and main slopes.

The city of Madrid sits on a moderately pronounced relief, with seven predominant hills and, as we saw previously, two connected troughs. A third depression could be identified under the Paseo de la Castellana, which practically separates Madrid into two halves.

The result of this orography is an incredible diversity of slopes, not prioritizing one orientation over another - except in specific places such as the riverbanks. This situation complicates the task of locating buildings in optimal orientations, since the orography - and the hierarchy of the concentric plot - has imposed very different street orientations. However, if it is possible to base urban practices that take this situation into account and facilitate buildings that are “easy” to orient, allowing to a greater extent those examples that we already have in the city and that have solved these conditions in a remarkable way. As we saw previously, the towers of Colonia de Lourdes, Saenz de Oiza, or the most celebrated Torres Blancas by the same architect, disconnect the difficulties of finding the best orientation thanks to their own specific condition. In any case, for urban typological diversity, further studies would be necessary to predict its best orientation and serve urban ordinances (Fernández-Antolin et al, 2019). All this referred to the influence of orography on the bioclimatic performance of buildings. Regarding the urban microclimate and the action of the orography in public spaces, the Madrid City Council offers in its Manual of Good Practices in Architecture and Urbanism some criteria for the location of green and urbanized areas that take into account such conditioning factors (Madrid, 2009).

2.1.10 Pavement permeability

Figure 21. Pavement permeability
(Madrid, 2009)

Another determining factor of the environment, which can be fundamental when it comes to refreshing public spaces, is the permeability of the pavements. Permeability is related to the passage of fluids through a material, with water and air being the most interesting for the object of study. Permeable pavements can absorb and store moisture that, due to the effect of solar radiation, is evaporated, generating a sensation of freshness in the user of the city. This strategy has been presented in some places in Madrid, such as parks and intra-urban road ditches. The Manual of Good Practices in Architecture and Urbanism of Madrid specifies permeability as one of the physical factors to consider when measuring the efficiency of evapotranspiration in summer in Madrid. Lower permeabilities of soils cause runoff, that is, superficial movements of rainwater, which are directed to drains and sewers. Grass, gravel, blocks with permeable joints, porous blocks or continuous porous pavements such as asphalt, concrete or resins can function as permeable soils.

2.1.11 Façade and flooring finishing

The finishings of the urban landscape also play an important role in the thermal performance of the built environment. Broadly speaking, such finishes can be on paved surfaces, buildings or green areas. Asphalt surfaces store a lot of heat during the day, which is returned to the atmosphere at night, increasing the chances of heat stress. The same can be said for buildings with dark finishes, or high thermal mass materials. If we pay attention to the thermal differences that can occur in the same Madrid neighborhood, we can see thermal differences of 3 degrees at distances not exceeding 100 meters. This great thermal heterogeneity insists on the ineffectiveness of urban-scale thermal maps to quantify the UHI phenomenon. In the vertical layer, the thermal differences occur at street level, where the different albedos of the surfaces generate more notable differences. Temperatures from 6 meters in height become unified, corresponding to a greater extent to the generic values that we know from the UHI cartographies (Tumini, 2012). With regard to climate adaptation, a city in which changes of radiant surfaces are implemented by those of lower albedo is a possibility to explore. Some projects, as we will explain in next chapter, are being oriented to this end.

2.2 Architectural scale

On the architectural scale, or building scale, we can also identify a series of climate adaptation strategies for the specific case of Madrid, which coexist with those mentioned above on the urban scale. At this point, and starting from the current situation of the consolidated built stock, it is interesting to evaluate the viability of some adaptation measures that could be designed and put into practice.

If we look at Givoni's chart for Madrid’s climate (Figure 22), we find quite a marked climatic variation between the cold and warm months, due in part to the remoteness of the watery masses and their inertial effect. Thus, in December, January and February, active heating systems are necessary, including conventional heating on the coldest days; the autumn and spring months can present moments of comfort -in September and May-, but they also need passive comfort strategies, such as thermal mass and ventilation in hot moments or internal gains in cold moments; in the summer months permanent ventilation is necessary, in addition to other strategies already mentioned such as evaporative cooling and even conventional cooling. These series of strategies can be very effective in controlling heat stress. If we focus on overheating situations, we can detail those corresponding to summer: natural ventilation, thermal mass, evaporative cooling and conventional cooling.

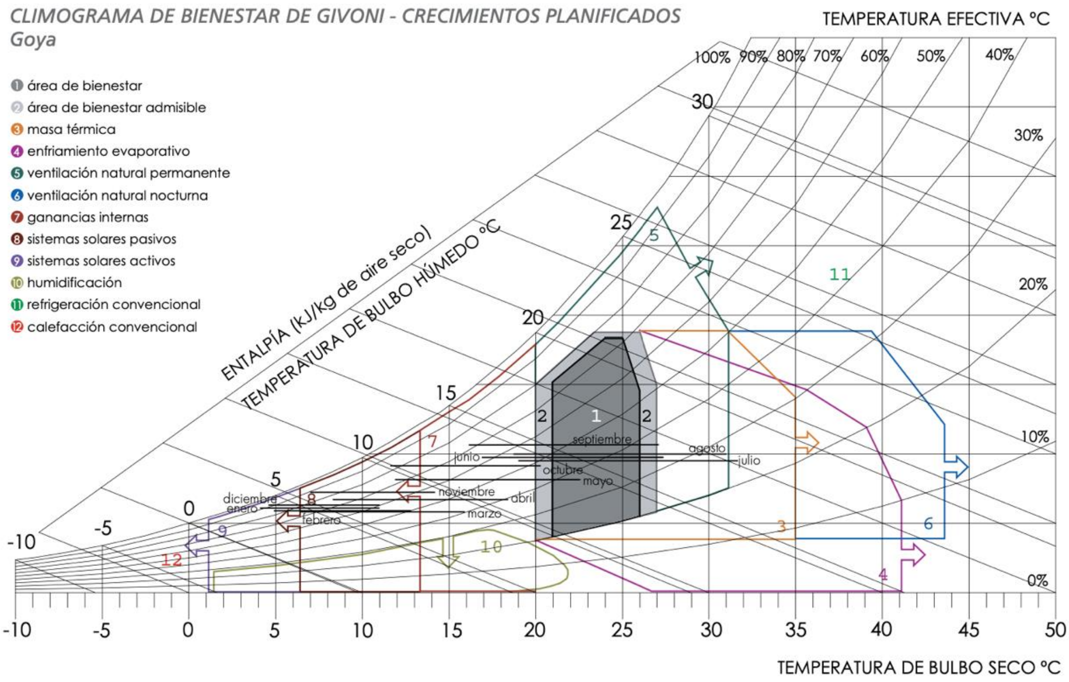


Figure 22. Givoni Chart, Goya, Madrid
(Madrid, 2009)

2.2.1 Natural ventilation

The passive cooling strategy by natural ventilation is highly recommended in places with a dry hot climate. This strategy assumes that it is sufficient to use air movement, for which the external conditions are considered valid or, due to air velocity itself, sensation of comfort is reached, as pointed out in Olgyay chart (Figure 3). In Madrid, the thermal difference between day and night can be applied to ventilate at night, incorporating fresh air and eliminating internal overheating in buildings. At the warmest time of the year, from mid-June to mid-August, the need to eliminate direct solar radiation from the openings, from 10:00 a.m. to the evening, induce them to be oriented east, south and west. The hours outside this slot can be used to introduce fresh air, through open and well-ventilated windows. The specific needs of solar protection and ventilation between some times of the day and others is resolved with blinds and awnings, being more advisable to use blinds at times of greater radiation, especially to the west. The interior distribution and the location of the ventilation openings in the buildings play an essential role, needing to face each other and with air paths that do not generate interior turbulence. The routes of the wind in Madrid can be diverse, depending on the immediate urban fabric, so it is difficult to establish a main direction for the incorporation of said peri-urban airs. There are currents generated in the directions of the riverside troughs, but these are only appreciable in areas close to them, and at street level. The hole orientation strategy, therefore, has more to do with the need for sun protection -in summer- and catchment -in winter. A correct management of radiation and ventilation can generate a sensation of quantifiable comfort at 4-6ºC.

2.2.2 Thermal mass

Thermal mass is the property of materials -in this case, building materials- that allows to store heat, providing “inertia” against temperature fluctuations. It is directly related to density and specific heat. Materials with more thermal mass will accumulate heat during the day -if they are exposed to Sun-, staying warm at night. In the same way as selective ventilation, the building's thermal mass can also play an important role in tempering interior spaces. On the one hand, the difference in the basements and semi-basements of the city is appreciable, which maintain more constant temperatures due to their contact with the surrounding terrain and the lower temperatures of the soil. But in the case of dwellings, the cooling effects of inertia are only noticeable in very massive buildings - such as institutional or religious buildings- in which the walls can be more than 50 cm wide and made of masonry. The vast majority of the built-up stock in the city of Madrid does not have these thermal characteristics. In fact, the strategy can act against the interests of reducing overheating, by returning accumulated heat to streets and buildings in dense areas. Sometimes this situation is solved by placing the materials with inertia towards the interior of the house, away from the capture of solar radiation, and others that are lighter and reflective outside. This situation can favor that the temperature curve from the interior is delayed up to 10 hours with respect to the exterior, and if it is combined with cooling by night ventilation, it can generate spaces that almost passively maintain interior comfort. In Madrid, we find strategies that take advantage of different inertias to favor optimal performance. Some examples are found in the office buildings around the airport, where the light and ventilated facades are joined by stone pavements and continuous contact with the ground (Madrid City Council, 2009).

2.2.3 Evaporative cooling.

Previously, we have attended to the mechanism of evaporative cooling on an urban scale, through the introduction of tree masses or blue infrastructure in the city. Evaporative cooling is a very valid strategy in Madrid, due to its low relative humidity. But how can this strategy be replicated in the building scale? An interesting possibility is the incorporation of green facades that, by surrounding the window openings, generate a permanent cooling layer in the immediate surroundings of the building (Figure 23). This promotes less exchanges with the hot environment as well, by functioning as a thermal buffer in which the temperature differences are not as high as with the outside. Placing planters with automatic watering on the façade is a similar and perhaps more economically viable strategy, and it has been proven in some of the best examples of residential architecture in the city. We find the same cooling strategy in buildings of different use than housing, such as bar terraces, industrial warehouses or offices, with different technologies. While in bar terraces we can find small drip irrigation type installations, in which the water expulsion parts have been replaced by pressure sprinklers, in offices or industrial warehouses machines that work under the same principle are used. The introduction of water in filaments and its interaction with the surrounding air causes heat exchanges on a microscopic scale, which result in the diminution of air temperature and the evaporation of water.

2.2.4 Conventional cooling

But, without a doubt, the most used strategy to cool down Madrid's domestic interiors is the installation of traditional air conditioning systems. A walk through Madrid, especially in the built surroundings of the M-30 or around the collective housing blocks on the periphery of the urban northern half, shows a large number of AC devices. And, although this technology has evolved considerably in recent years, operation is still basically detrimental to the objectives of minimizing the urban overheating effect. By installing two devices, one inside the houses and the other outside, a closed circuit is established in which heat exchanges with the environment take place. Thanks to the compression and expansion of a fluid, energy is captured or expelled from the environment -cooling or heating it, respectively. Thus, while inside homes, shopping centers, bars, sports facilities or other facilities the conditions can be cool, outside this produces an increase in temperature. Therefore, overall, cooling systems are detrimental, generating thermal sub-islands in those places where there is a higher density. In Madrid this happens mainly in the industrial areas of the south, as well as in those places with large commercial buildings (see map of inefficient buildings distribution). The replacement of air conditioners is still difficult for the city to promote, as they are widely used by the population and provide quick comfort on hot days. There are, however, sustainable active cooling solutions that could be explored for an urban future, consisting of geothermal wells or heat recovery systems.

2.3 User scale

The third scale on which we can find adaptation strategies to the urban climate is that of the user. Some of the recommendations of the Madrid authorities address precisely this scale in their emergency plans against heat waves. Given the difficulty of implementing adaptive strategies in the two previous scales, due to their difficult technical or economic feasibility, the focus is on small strategies, modes of use, and routines that can minimize the risks of suffering from heat stress on the most vulnerable part of the population. We summarize here routines that have to do with the built environment, and can be understood as actions related to architecture. They are divided into 2 sections, paying attention to Madrid architecture: schedules and spaces.

2.3.1 Schedule

The hourly temperature values of the city of Madrid in summer result in considerable differences depending on the location of the building. In the areas most affected by the UHI, nighttime temperatures hardly differ from daytime temperatures, making cooling by natural ventilation difficult. In the rest of the places, a correct management of the openings - shading and / or opening - can be crucial. Madrid homes have -climatically required- blind and/or awning systems. At night, it is recommended to fully open the windows on the facing facades, to maximize the effect of cross ventilation, raise blinds and awnings. Starting at 10:00 AM, when temperatures begin to rise, it is recommended to lower the awnings and blinds, keeping the windows open to produce light ventilation. For the elderly, it is recommended not to go outside in the hottest hours of the day -from 12h to 17h-. Sun protection is especially relevant at the evening, to the northwest in summer, since direct solar radiation itself is added to the overheating produced by the accumulation of radiation throughout the day, generating situations of excessive heating.

The blinds of the house where solar radiation is no longer expected can be opened, keeping those oriented at sunset closed, until there is no sun. Around 11pm the temperature begins to drop again.

2.3.2 Spaces.

Similarly, the use of spaces depends on their orientation and their degree of ventilation. In traditional Madrid dwellings -*corralas*-, it is common to see neighbors in the patios, where the shade and inertia of the building generates a slightly more refreshing sensation during the day, due to the abovementioned evaporative cooling effect. In some neighborhood communities, this circumstance is used to irrigate the patio floor, or the access hallways, generating coolness by evapotranspiration. Again, it is advisable to avoid the most overheated areas, facing west, where solar radiation increases high temperatures due to environmental inertia. On an urban scale, this translates into the choice of the shaded paths, by building or by trees. It is also recommended that the aging population know the coolest places near their homes, to be able to go in case of need (cinemas, supermarkets, libraries, social centers ...). In this sense, public facilities play an important role, sheltering the vulnerable population in more comfortable spaces.

The climate adaptation strategies seen on the preceding pages give an idea of what the practices to be strengthened from the different scales may be. Thus, the responsibility for applying them fluctuates between politicians and administrations - in the case of urban practices - technicians and architects - in the case of building technologies - and the residents of the city themselves - in the case of daily adaptation actions. Every level of action is, in any case, closely related to the other: the possibility of having a fresh patio, populating it with flowers and autonomous watering, depends so much on the ordinances, on architectural designs, on the responsible maintenance of the neighbors. The sum of strategies can generate sensible temperature differences of 5 to 8º. If we start from the existing climate data, this produces added complexity when assessing the effect of the UHI on the city. Small strategies, or the availability of certain facilities in the building, alter the generic image of the island, transforming itself towards the situated and the concrete. To correctly analyze a city, with its multiplicity and casuistry, it would be more recommendable to choose to select a sample, a human group or a certain architectural setting, and assess it from urban issues -degree of greening of the street, orientation, construction typology-, through architectural issues - insulation of facades, type of glass, shading of the gaps - to issues of use - hours, adaptation techniques used, plant irrigation, ventilation management, activity. All this casuistry generates effects on the final sensation of thermal stress, and speaks of the richness and complexity of the citizens' relationship with the climate. Architecture and urbanism act as an agent in a urban-climate assemblage, where the individual scale to the mesoclimatic scale transfers and interactions occur.

Once this survey of the problem of heat management in the city of Madrid has been carried out, in which it has been explaind what the current situation is at the regulatory, built and climate level -in chapter 1- and what are the possibilities of adaptation strategies in overheated parts of the city -in chapter 2-, we are now going to have a look at the initiatives that have been taking place for a little over 10 years at the political level and that have an effect on the city's interaction with heat. Thus, the third chapter is mainly in oriented to that purpose: collecting and exploring the regulations, projects and climate management plans that have an effect on the city of Madrid.

Chapter 3.

Policies for the adaptation to thermal stress in Madrid

In this third chapter, an analysis is made of the climate adaptation measures and policies promoted in recent years in the city of Madrid, and which have an effect on architecture and urban planning. The chapter tries to engage with the following question: from the perspective of the architecture of the city, what have been the projects, measures and public initiatives that tackle the problem of urban overheating? As we have seen, the built landscape, the different types of buildings, the urban morphology, the arboreal or watery masses, generate an effect on the human communities that inhabit the spaces. Interactions with climate are established through multiple scales, and situations of overheating or thermal comfort are resolved in heterogeneous materialized phenomena: from urban regulations, to architectural design or daily actions. Architecture plays a role in the way humans relate to non-humans, participating in the creation or recreation of (civil) order and ecopolitical arrangements (Dominguez and Fogué, 2015). Architecture is not a static framework in which people live and "suffer", but rather part of a chain of events and situations, and interacts with them. It is modifiable, and it can perform in different ways depending on issues such as usage or context. Understanding the urban built stock not as something static, but as something dynamic, changing, provided with a certain instability, participant in controversial issues (Yaneva, 2010), facilitates the conceptual framework from which to assess adaptation strategies and evaluate policies. If we accept as valid the statement that there are no longer backgrounds (or contexts, architecture) and objects (or subjects, society), or what is the same, that architecture and the built city is not a static framework in which societies live (Jaque, 2011), but rather something inserted into problematic issues, such as that of Climate Change, and that that interaction occurs through -among other issues- our daily practices of micro-management of heat, the building rehabilitation policies that we socially validate or the growing concerns about energy consumption, we may understand that the flexibility of the built landscape can give space to resilience and mitigation of Climate Change in the city, as well as a whole different way of relating with climate. Attending to urban policies happens here because of its condition as an architectural agent, capable of transforming some of the inefficiency conditions explained in the preceding pages.

In the first place, we attend to the most interesting initiatives within the European framework, as well as the most relevant directives regarding energy transition and climate change in the city. Later a summary on the Spanish agenda on the same topics is carried out, briefly explaining the operation of urban planning laws in Spain. Finally, and in greater detail, we review the impact of the previous frameworks on the city of Madrid, paying special attention to three levels of initiatives, which mark an upward line in the materialization of climate concerns: from public reports, through action plans to real projects.

3.1 European framework.

The objective of this paper is not to carry out an exhaustive analysis of the measures promoted by the EU to attend situations of urban overheating, but to name the initiatives that are considered most relevant:

- Urban ERA-NET. In 2009, a pilot study was carried out at European level on the action of the built city on thermal stress situations. Taking Gothenburg (Sweden) as the scenario, this experiment serves to initiate a series of simultaneous conversations and investigations between different groups that consolidate in the formalization of the Urban ERA-NET research network, dedicated to the study of urban climate, climatic comfort and risks and opportunities. from urban planning.

- Simultaneously, the Reference Framework for Sustainable Cities (RFSC) is being developed in Europe, by mandate of the Ministers of Urban Development of the EU. It is a tool -of voluntary use- that serves to guide developers and urban planners in questions of integral urban sustainability. It consists of a series of indicators and visualization tools.

- In 2016 the most ambitious initiative in urban matters in the EU was created: the New Urban Agenda. It focuses on cities as engines of sustainable development, focusing on some issues such as urban mobility, energy transition, or climate adaptation. The aim of the New Urban Agenda is to offer standards and principles for the construction in Europe and the development of the cities of the future.

Nowadays, the most ambitious measures in response to climate change are focused on 2030, with an expected reduction of 55% in greenhouse gas emissions, to reach climate neutrality in 2050. Some countries, such as Spain, are already legislating to comply with such precepts (BOE, 2021). In the Directive of May 30, 2018 of the European Parliament, on the energy efficiency of buildings, specific requirements for promoting renewable energy and buildings with almost zero consumption where stablished.

3.2 Spanish agenda

As have been explained throughout this report, Spanish technical building regulations have an unquestionable effect on the quality and thermal performance of buildings in Madrid. Thus, the succession of increasingly restrictive regulations (from NB-CT 79 to CTE HE 2019) promotes more sustainable and healthy spaces. In the latest version of the CTE HE, which specifies the mandatory technical requirements on the energy performance of buildings, EECN (nearly Zero Energy Buildings) performance is pursued. We can see how, over the decades, concerns about the hygrothermal functioning of the buildings have not only resolved to increase the requirements for thermal insulation, but have also been accompanied by others on energy efficiency, which lead to new regulations on maximum permitted consumption and types of energy incorporated into the buildings. This has an obvious - but not immediate - effect on urban overheating situations. As we have explained, thermal stress occurs due to the action of multiple elements: insufficient insulation, poor ventilation, unwanted orientation, urban fabric, greenery, etc. The regulations that oblige new buildings to consume less energy and be more self-sufficient spaces suggest environments that are less populated by air conditioners, resulting in lower rates of UHI effect. However, this situation is only to be expected in new housing developments, located in peripheral areas where precisely the UHI effect is less harmful. In order to find more effective measures in combating overheating situations within the urban perimeter, it is necessary to attend to those that affect the actual city.

Between 2010 and 2012 we found a series of interesting initiatives, which mark the interests of Spanish urban planning, in which those principles, objectives, guides or examples to make cities more environmentally sustainable spaces stand out. In 2010, the White Paper on Sustainability in Spanish Urban Planning was published, in which non-binding proposals are reflected. The same character has the Spanish Strategy for Urban and Local Sustainability (2011) and The Green Paper (2012). These documents can be understood as the verification of a state of the question, a series of concerns, which are consolidated towards the Spanish Urban Agenda (2019) and in the form of regional local development projects, such as the municipalities with EDUSI strategies (*Estrategia de Desarrollo Urbano Sostenible e Integrado*) in Spain. Thanks to European funding, numerous improvement projects are carried out which, although they do not have a transversal effect on the management of urban overwarming, do serve to expand green areas, pedestrian areas or urban blue infrastructure in many places. The Spanish Urban Agenda serves as a strategic framework from which to guide the different cities in terms of urban sustainability, and is a reflection of the European Urban Agenda, in a local key.

The point is that, in Spain, urban planning is not integrated into a centralized public administration, but depends on each municipality. In accordance with state laws, each Spanish city draws up its urban regulations. Such regulations are divided into different types, of which the highest hierarchy is the General Urban Development Plan (PGOU). The PGOU establishes such fundamental issues as the urban plot and density, spatialization of green areas and roads, facilities, etc. That is why at a national level it is difficult to establish norms on the design of the city -new or consolidated-, with each city council responsible for such decisions. This results in an endless constellation of urban plans, with greater or lesser sensitivities towards the issues we are dealing with here. The issue of urban warming is managed from multiple forums, with very diverse interests and precedent knowledges. However, some Spanish laws provide a framework to which different cities, including Madrid, must abide by. The two most relevant laws regarding urban heat stress management are listed below:

RDL 7/2015.

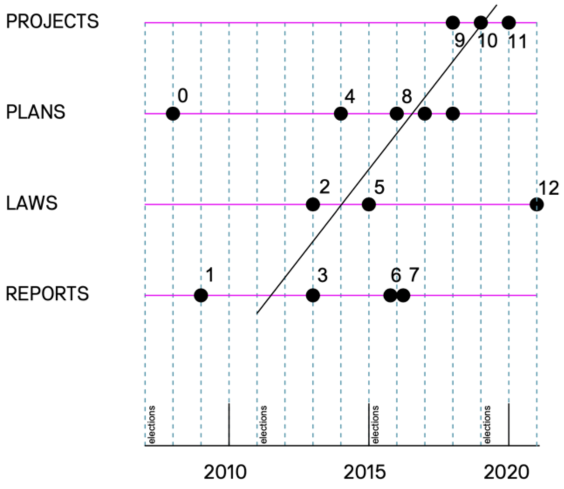
Heir to the Urban Rehabilitation Law of 2012, in 2015 the Land and Urban Rehabilitation Law was approved, the objective of which is to promote and facilitate the rehabilitation of buildings and the regeneration of the existing urban fabric to ensure citizens quality of life and rights to decent housing. In relation to overheated houses in cities, thermal insulation installation actions are facilitated to reduce the demand for heating or cooling, and the installation of renewable energy on the roofs of the buildings is facilitated to minimize energy consumption. Another matter of interest is that it is obliged to attend to people with risks of mortality and morbidity derived from high temperatures in the management of land uses. This may mean, for example, prioritizing districts with older people when proposing new green areas in the city (BOE, 2015).

Ley 7/2021.

The Climate Change and Energy Transition Law is added to some of the measures described in the previous law, in addition to focusing with more emphasis on the production and consumption of energy in Spain. Set by the objectives of the Paris Agreement of 2015, it mobilizes funds to improve the energy efficiency of buildings, which means again facilitating the installation of insulation and renewable energy systems and low consumption. The Law announces a Housing Rehabilitation Plan that must specify and operationalize these objectives (BOE, 2021).

3.3 Madrid reports, plans and projects.

Once the state of the art regarding adaptation to climate change and thermal stress in cities has been analyzed, it is worth asking what level of appropriation these guides, plans and objectives have had in the city of Madrid. In order to review those public initiatives that have been carried out or are being carried out in the city, it is convenient to organize them according to their nature. The following table contains a series of proposals promoted by local administrations (Madrid City Council or Community of Madrid) depending on whether they are reports, plans or projects.



1. Madrid,City Council. "Good Practices in Architecture and Urbanism for Madrid. Bioclimatic and energy efficiency criteria." (2009)
2. Law 8/2013 of urban rehabilitation, regeneration and renewal (energy efficiency)
3. Madrid, City Council. Review of the General Urban Plan. Environmental Sustainability Report (2013)
0. y 4. Madrid, City Council. Plan for the sustainable use of energy and prevention of climate change for the city of Madrid. Horizon 2012 (2008) Horizon 2020 (2014)
5. LeyRDL 7/2015. Land and Urban Rehabilitation Law
6. Madrid, City Council, and Autonomous University of Madrid. Urban Climate Detail Study (2016)
7. Madrid, City Council. Technical study on energy poverty in the city of Madrid (2016)
8. Madrid, City Council. Mad-re *Madrid Recupera* Plan (2016,2017, 2018)
9. Madrid, City Council. Central Madrid, Low Emissions Zone (2018)
10. Madrid + Natural Solutions. (2019)
11. Madrid, City Council. Madrid, *Isla de Color* . (2020)
12. Law 7/2021, of May 20, on climate change and energy transition.

Figure 23. Reports, laws, plans and public projects for Madrid regarding sustainability.

This division makes it possible to trace a growing trajectory of materialization of public concerns regarding urban overheating, and more generally, about the sustainability of the city model (Figure 23). The nature of the reports is precisely to inform on a certain situation that it is necessary to know, and on whose purpose bases its study. Urban plans stand out as framework documents that establish a certain strategy that should govern decisions about the management of the city in its multiple dimensions. From there, the concrete projects show materializations with a definitive character, which are re-drawing the urban panorama and its relationship with the issues in question. In this case, the most relevant aspects in terms of adaptation to overheating of the initiatives will be highlighted, assessing their relevance and level of adaptation to the problem. In this, due to the lack of conclusive data, we use the notions collected in the reference pages, regarding what should be understood as effective measures to minimize overheating in the different scenarios of the city.

The presented table allows us to intuit three stages in terms of the public management of urban overheating: a first stage, of *first steps*, between 2009 and 2014; a second stage, *planning*, between 2014 and 2018; and a third stage, of *actions*, from 2018 to the present days. This identification stems from the nature of initiatives promoted by the administrations in the different time segments. Between 2009 and 2014, a series of reports were released, which would mark the development of planning between 2014 and 2018, currently being a time when a greater number of projects related to the problem in question are identified.

First steps, 2009-2014

As previously mentioned, at the European level it was not until 2009 that the first studies on thermal stress in the city were carried out, taking into account different scenarios (Thorsson et al, 2009). Urban bioclimatic issues are still emerging knowledges, which were presented for the first time in Madrid in a guide document published in 2009. Some of the most prominent architects and climate scientist in the city participated in it. Specially relevant is the authorship of Ester Higueras, responsible for the first bioclimatic ordinance in Madrid region (Higueras, 2009). The aim of the document is to serve as a conceptual guide for future urban planning developments in Madrid. For the first time in a report from the municipal authorities, topics such as the Givoni chart, the solar obstruction angle or thermal inertia are discussed. It serves as a compilation of design strategies and guidelines that are essential to support architectural practices that minimize energy demand, insisting on passive performing of buildings. The guide, although novel for its time, nevertheless remains as a mere presentation of the characterization of Madrid's climate, the general action of its architecture and urban fabric and possible lines of improvement, embodied as examples of built places in the city. By dealing with matters in a more generic way, it loses power as a design tool, which would ultimately be conditioned by a complex and concrete casuistry. The book stands out as the compilation of a set of good practices, which can be useful in a generic way for climate management in the field of architecture and urban planning.

Another noteworthy document of this first stage is, without a doubt, the Review of the General Plan, Environmental Sustainability Report, 2013. As its name indicates, it is a review document of the 1997 PGOU, which is the normative document that regulates the urban planning of the city of Madrid. From an environmental point of view, this report is presented as an update of the premises that should govern the development of the city, incorporating urban sustainability issues, which in the moment of the PGOU were not as socially and politically relevant as 25 years later. The purpose of the Review is to evaluate the environmental effects of the General Plan, taking into account aspects such as biodiversity, population, public health, etc. proposing measures to reduce the environmental impact of the city and integrating sustainability criteria.

In relation to thermal stress, the document indicates a series of "polyvulnerable" polygons in the city, where aspects such as the degree of exposure to the UHI effect, the green factor of the closer surroundings, the aging or low-resource population, or the constructive quality of the built stock are taken into account. As has been reiterated at different times in this report, this last criterion is analyzed according to the year of construction - prior to 1980 - and by the property's cadastral value. Presumably higher value buildings tend to be better preserved, regardless of their year of construction. Regarding the factors of social vulnerability due to greater exposure to the UHI, the report indicates those areas that are the most affected ones (Arganzuela, Vallecas, Usera and Villaverde), and briefly points to something that has already been emphasized in this report: the different scales of impact in the problem of thermal stress: while the geographical location is presented as a first level of risk, others must be taken into account, such as the presence of urban trees or the quality of the building.

Another relevant analysis carried out by the Review is a cartography of the most inefficient buildings -as shown in Figure 19-, understanding as such those whose energy exchange with the environment generates the greatest thermal differences on their roofs. This happens due to the action of air conditioners, which expel hot air to the outside to cool down the interior spaces. The most inefficient buildings are those that need more energy to maintain indoor thermal comfort, and whose passive performativity is far from enough. This may be due to factors such as a lack of thermal insulation, excessive or poorly oriented glazed surfaces, or poor ventilation, among other. By requiring devices to ensure comfort that consume a lot of energy, they dissipate a lot of heat to their surroundings, increasing temperatures outdoors. The geolocation of this type of phenomena in the city is a very important step for founding proposals to reduce heat in the city. In this sense, the Review provides a proposal for measures to increase the green factor on an urban scale, which takes into account precisely the location of these “energy sinks”, in addition to the aforementioned polyvulnerable polygons. For the first

time, we see a comprehensive planning proposal, in which various risk factors are being taken into account. The debit that is presented in this document is an analysis of the viability of this increase in the green factor that, although it is considered opportune and correct, presents doubts regarding its materialization.
In any case, the 2013 Environmental Sustainability Report is a milestone for the subsequent development of specific policies and the mobilization of tangible and intangible resources, as we will explain below.

Within this first stage of Madrid`s initiatives, in which reports and studies on the thermal and energy performance of the city were developed, there are also Plans for the Sustainable Use of Energy, in 2008 and 2014. In those documents, local administrations commit to the reductions in greenhouse gas emissions required by European authorities, according to Horizon 2012 and Horizon 2020 objectives. The measures presented in these plans clearly would affect the UHI effect, since the reduction of these gases not only has positive effects on the health, but also on the ability of the urban atmosphere to dissipate heat. However, the degree of application remains unclear, as there is no final evaluation publicly available.

2014-2018 Planning

Once some issues on overheating and energy performance are identified, the administrations progress to a second stage. Reports serve for new plans, that have stronger effect on the future city. At this moment, what is important is to start working within the confinements of the city, not from a theoretical standpoint, but rather from a specific and situated perspective, based on the use of it and the lived experiences of its inhabitants. The change of administration produces a change of interest towards the periphery, which becomes more recognized in municipal plans from various areas, such as culture, tourism, mobility ... Regarding the management of the UHI phenomenon, the first direct aid to the rehabilitation of buildings is presented, through the Mad-Re plan, *Madrid Recupera*.

Mad-Re arises as an annual plan to support energy rehabilitation, accessibility or building projects for communities in vulnerable areas. To identify most-in-need areas, the plan is based on the mapping carried out by the 2013 Report, largely adjusting to the polyvulnerable areas that were presented previously. In this case, they are called Preferential Areas to Promote Urban Regeneration (*APIRU areas*), and are determined by socioeconomic indicators (such as unemployed, uneducated or aged people), economic indicators, building indicators (the value according to Cadastre, accessibility, year of construction, overcrowding index) and urban indicators (green areas, urban accessibility, acoustic comfort). In these APIRU areas, the municipality subsidizes, by annual call, regeneration measures such as the installation of elevators, the isolation of the facades, change of roofs or various repairs. The first call was in 2016, the second in 2017 and the third in 2018. At the same time as the results were shown, the city council drafted in 2018 a document in which a city model is proposed, based on the programming of a series of actions, which is a further step with respect to the 2013 Environmental Report.

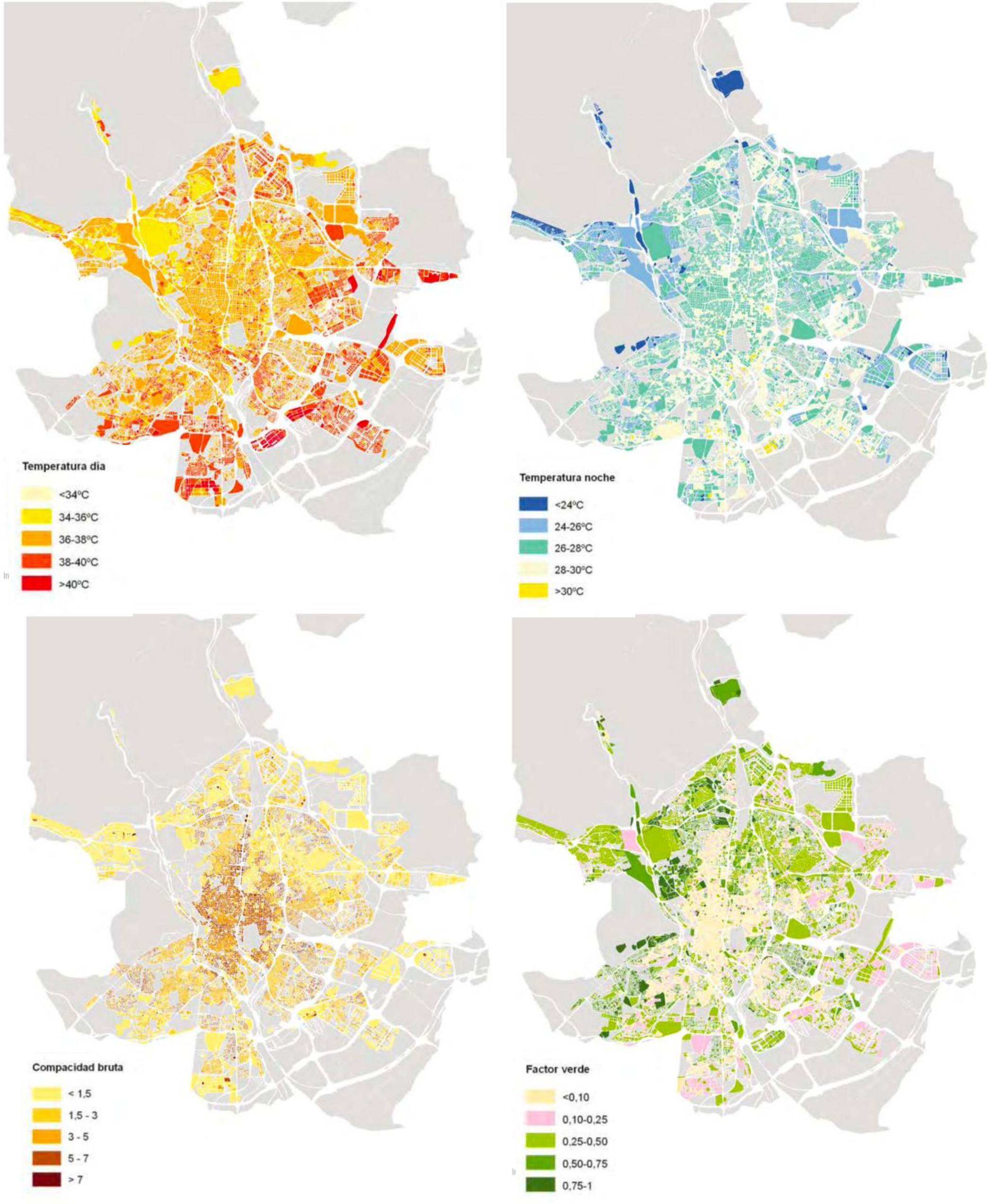


Figure 24. Mad-Re cartographies. Day temperature, night temperature, compacity and green factor (Madrid, 2018)

Regarding the UHI effect, the plan is based on a new urban heat island analysis and a series of related indicators (Figure 24). Thus, it identifies the most compact spaces and those with the best greened areas, to verify that the densest areas with the least green factor are located in the urban center and in some peripheries with a closed block typology -which usually correspond to H-shaped buildings that we explained earlier- where the heat island gets more extreme. By doing so, it points at the surroundings of the M-30 as the most exposed places, in which the asphalt of the highway also plays an important role. Again, districts such as Arganzuela, Vallecas or Usera and Villaverde are indicated. It also provides a cartography that locates the density of aging people in the urban fabric.

In its analysis of the results of the economic aids given for 2016 and 2017, it is striking that, despite being distributed throughout the city, the type of aid is mostly frequently for accessibility, that is, for the installation of exterior lifts (Figure 25). This may indicate a greater degree of concern, due to the embodied experiences of the neighbors, of the limitation of not having this type of means, and a greater distancing towards the issues of thermal comfort inside the homes, which ultimately can be solved by increasing the electricity bill. Of course, accessibility and insulation of facades can affect, for different reasons, the sensation of thermal stress inside buildings, due to factors derived from physical activity -in the first case- and the energy performance of the building -in the second. The improvement of accessibility can also be prioritized by the greater technical ease of its execution, being the placement of all continuous insulation a more complicated matter, in which the degree of conservation of the existing building intervenes in a more generalized way. Also, undoubtedly, the fact that the covered percentage of the operation rose to 70% could encourage the application for this type of aid, with an average of 55% for energy improvement.

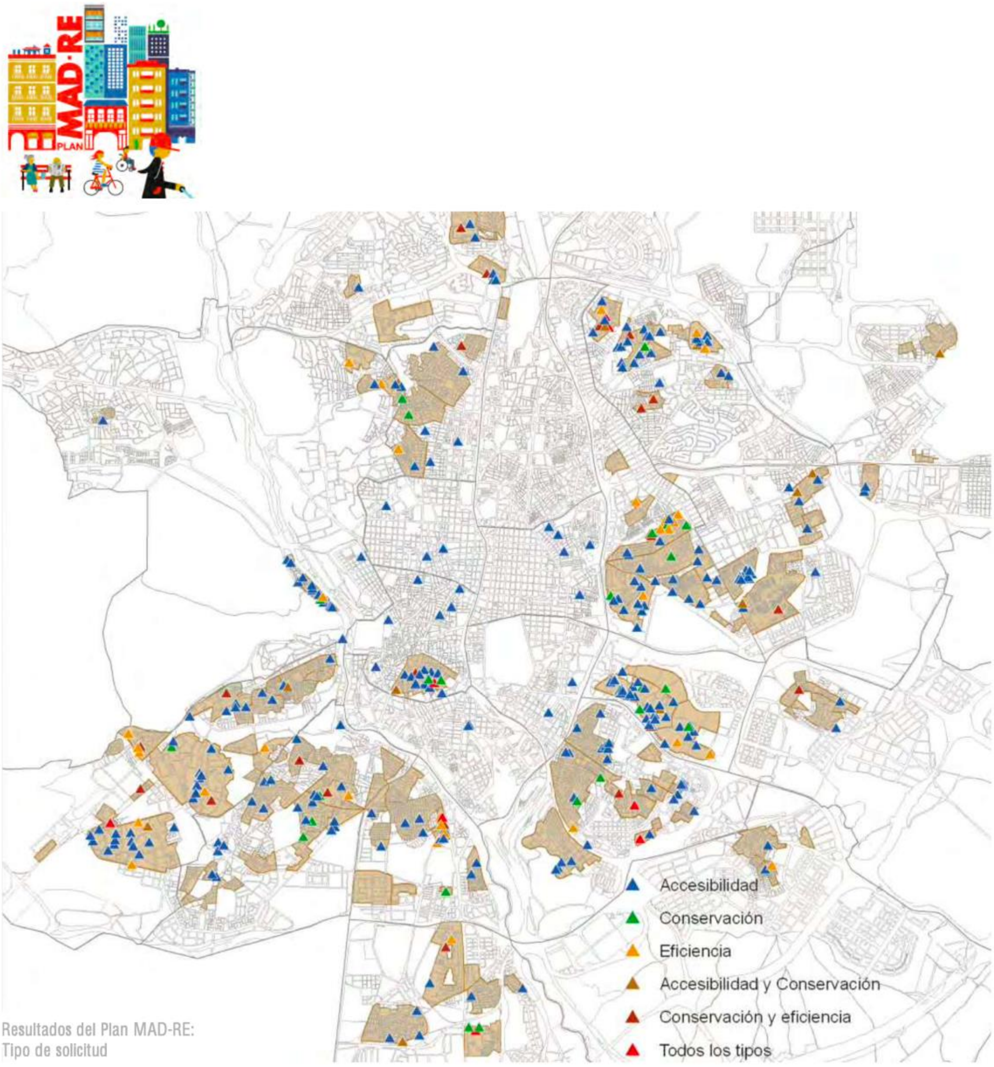


Figure 25. APIRUS Areas, location of retrofitted buildings and type of grant.
Blue: Accessibility, Green: Conservation, Yellow: Efficiency, Red: All tyes
(Madrid, 2018)

Another issue that draws attention is the low participation of the southern districts in this type of aid. This may be caused by the presence of less cohesive communities in that part of the city, or more impoverished ones. It can be seen how in some of the aforementioned districts -mainly in Vallecas- there are numerous aid concessions. The amount of aid for APIRU areas, in any case, would never exceed a maximum of 10,000 euros, for accessibility aids, and 8000 for those for energy rehabilitation, being able to deprive communities with lower income levels of this possibility south of the city.

In any case, the Plan carries out its own diagnosis - similar to that of 2013, but with a greater level of detail - and identifies a series of networks that should guide urban development in the peripheries, to provide them with higher urban quality. These networks are those of proximity - which link neighborhood facilities - those of identity - that link landmarks and relevant spaces of the neighborhood - those of an environmental nature - that link parks and boulevards - and mobility - that link metro, bus and metro stations among other means of public transport.

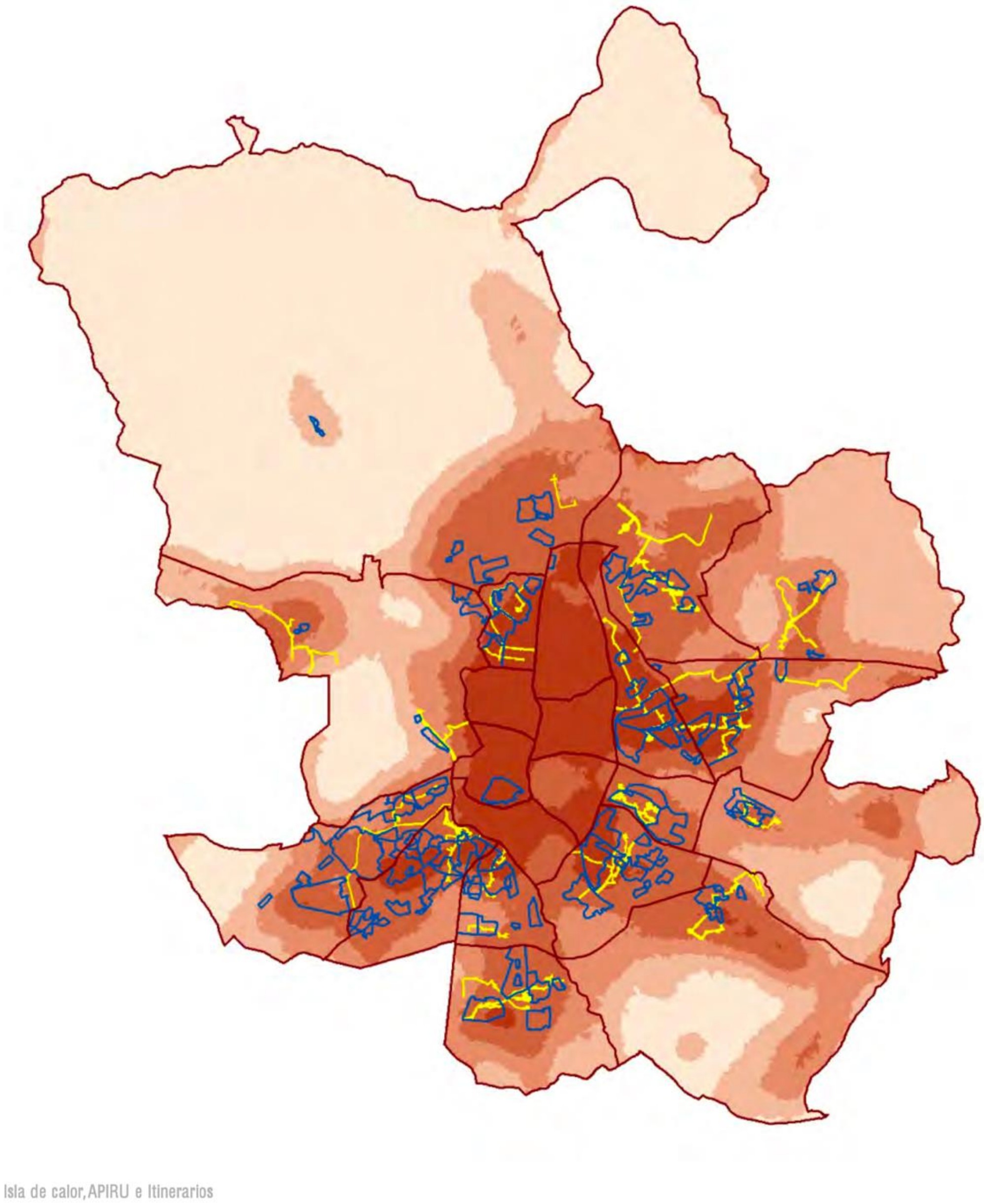


Figure 26. Heat Island cartography, green corridors (yellow) and APIRUS areas (blue). (Madrid, 2018)

These networks become Habitable Itineraries in the plan, which are identifiable paths with a double objective: "to achieve a more walkable city and the bioclimatic strategy of improving the conditions of the UHI" (Madrid City Council, 2018, p.80). Through the recovery of the pedestrian scale, the plan seeks to guarantee proximity mobility that also works as green corridors that connect parks and green areas, using tree-lined paths and permeable pavements. These measures have broad potential to minimize the effects of the UHI, as we explained in the previous chapter. Green areas act as freshing urban elements, due to their ability to minimize radiation on asphalt and sidewalks and, in the same way as permeable soils, due to the cooling action of the evapotranspiration of the water they capture. The itineraries that are proposed in Mad-Re plan traverse the most compact urban areas (Figure 26) and improve the comfort conditions, influencing the temperature and humidity parameters. The map provided for this purpose is spatially relevant, on page 82 of the document, in which the APIRU areas, the UHI distribution and the proposed itineraries are superimposed. The level of execution of the ambitious itinerary plan is, however, quite uneven. The change of administration that took place shortly after the Mad-Re Plan was drawn up produced a change in priorities with respect to the urban periphery. However, there are appreciable initiatives on the Del Río to Pradolongo itinerary, the Miradores itinerary or the Madrid-Río -Parque de San Isidro itinerary. For a correct evaluation of this strategy, a detailed study of these projects should be carried out.

In the last years of Manuela Carmena's government, some urban interventions were carried out aimed at achieving the plans presented. After 2018, in terms of mitigation of urban overheating, we are moving to a new the stage of actions.

Actions. 2018-2021

Undoubtedly the most controversial and transformative action of the Manuela Carmena administration was the materialization of the Madrid Central Low Emissions Zone. It is not the objective of this work to carry out an exhaustive analysis of the controversy associated with the plan, its degree of implementation and appropriation or its repercussions, but it is to point out that the measure was taken with the objective of improving air quality, but also of granting to the urban center of more pedestrian areas, reduce noise and improve the microclimatic performance of the center. Air pollution in the city of Madrid was, and is, a perturbing issue that generates a considerable increase in mortality (Khomenko et al. 2021), and the project was presented as an effective measure to minimize the action of one of the major urban chimneys: the central area. It is currently in a moment of transformation, having been appealed to justice by the current

City Council to establish another project with very similar characteristics. The urban billboards and signage will be replaced, if everything continues as presented, by the new “brand”.

We must also highlight among the actions of this last stage, although not all belong to that time period, the projects developed within the initiative of *Madrid* + *Natural* program. In 2016, within the local strategy for adaptation to climate change that we have explained previously, in which the APIRU areas were identified and direct aid for rehabilitation began to be granted, the Madrid + Natural program was presented as an initiative to promote actions that would implement nature-based solutions on three scales: building, neighborhood and city. The objective of the program was to integrate nature as a mechanism to mitigate the impacts derived from climate change, long droughts and the increasing duration and intensity of heat waves. The collection of actions that are included in the program justifying document -a total of almost 50- exemplify some of the strategies already mentioned in this report: more green areas in streets, facades and roofs, resilient urbanism, naturalized infrastructures, microclimates with water, seasonal shading, permeable surfaces, change of roofing materials, etc.

For a correct evaluation of these projects, measurements would be necessary, but whose obtaining seems outside the scope of this work. However, the geolocation of the projects included within Madrid + Natural allow a priori evaluations to be made. Contrary to the cartography presented in the Mad-Re Plan, relating to Habitable Itineraries, we find in the Madrid + Natural projects with a clear predominance of the urban center, as well as the outermost and newer areas of the city. The ring of buildings built between 1940 and 1980 remains unheard of for this type of nature-integration operations. This may be due to their dependence on private initiative, which tend to locate their interventions in places with higher market values. In the overheated districts mentioned, Vallecas, Usera or Villaverde, there are no M + N projects.

More recently, the plan of the new City Council to deal with the situation of urban overheating has been announced. It does not mention the previous plans, nor the Madrid + Natural projects nor the Mad-Re plan. In the graphic communication the shape of the Urban Heat Island is reflected on an aerial photo of the city, placing on its right another image in which the oranges and reds are replaced by green colors. "From the Island of Heat to the Island of Color," announces the plan's slogan. The project speaks of “leaving behind the idea of Madrid as a space affected by climate change, polluted and that depletes its soils through unsustainable uses. To abandon the heat island and transform it into a green island”. This same communication is somewhat confusing, since the UHI seems to be considered as an idea, tacitly denying its effects. However, as we have been able to glimpse throughout the preceding pages, the issue of the Island of Heat is something very tangible and the mitigation of which is undoubtedly more complex than a chromatic issue. Heat, as an embodied agent, which is expressed in the lived and situated experiences of the inhabitants of the city, has many differences with the color, green, which, however, is instrumentalized in the official communication of the City Council.

Madrid Isla de Color has several lines of action, among which the Metropolitan Forest stands out: a proposal for the ecological recovery of the margins of the city, in the surroundings of the M-40 highway, which bypasses the city (Madrid City Council, 2020). The projects that will be part of the Metropolitan Forest were the winners of an international competition, where architecture and urban planning teams participated. The quality of the winning proposals is clear, but it remains to be seen the level of development they will have in the coming years. In any case, attending to the purposes of this report, the Metropolitan Forest projects do not face the problem of urban thermal stress, as they are located far away from the places where the phenomenon is most intense. But, as we have seen, the formation of urban microclimates is related to a multitude of factors and, without a doubt, establishing green cords -although far from the center- can generate positive effects at the level of quality and freshness of the peri-urban air, which enters the city by the action of air currents. If we look at proposals for energy and climate improvement within the city limits, in neighborhoods where the effect of the UHI is greater, we only find a brief infographic that, under the slogan *Barrios Productores*, proposes to recover urban voids, inter-block spaces and flat roofs of buildings. However, in this documentation there is no specific planimetry that develops such proposals, or analysis of their possible effects.

3.4 Older adults and thermal stress in Madrid.

Older adults are more vulnerable to heat stress than the general population (Basu. 2009). If we look at the management of specific overheating in the population of older adults, the Community of Madrid has an Emergency Plan, applicable annually between June 1 and September 15, when maximum temperature values are expected (Community of Madrid, 2019). The plan highlights the increase in people over 80 years of age, which require “continuous improvement of the surveillance and control plans of the effects of heat waves” (Idem, 2019. p.5). For this reason, the contents of the plan are transferred in detail to residences for the older adults and professionals of social services in the city. Considered as the “target population” of the intervention plan, special attention is paid to those who meet some of the most fragile characteristics (living alone, having cognitive problems, being in medical treatment, low socio-economic status, etc.). From an architectural point of view, it is interesting to note that older citizens who "live on the top floors of houses without an elevator and without air conditioning" are also considered especially fragile (p.15). As we have seen previously, thermal stress conditions can be aggravated by, among others, those three conditioning factors of the building: high floors such as those in which heat tends to accumulate, the absence of an elevator as a factor in increasing the metabolic rate, and air conditioning as a guarantor of cool conditions despite the detrimental consequences for the thermal qualities of public space. Some of the plan's recommendations and considerations are also interesting from an architectural and city point of view. The recommendations have a lot to do with those adaptation strategies from the user's scale, which were indicated previously: use of blinds and awnings to minimize solar radiation, knowledge of the refrigerated places closest to the house to go in case of need (supermarkets, cinemas, museums, etc.), adaptation of walking hours to hours with less solar incidence, use of water to refresh the body, etc.

In any case, beyond those approaches to heat management from urban planning and architecture, indicated in the different municipal plans and projects, there is no such thing as an "architecture oriented to adaptation to heat in the elderly", or urban planning for this purpose. Obviously, bioclimatic architecture, under standards such as the *Passivehaus* one, has been dedicated in many cases to new construction of Residences for the elderly. The effects of this type of architecture on interior comfort and on reducing the energy demand of the building are proven. For vulnerable population, designed spaces that eliminate thermal discomfort factors such as those we saw at the beginning of the report (not only temperature or relative humidity, but also the correct balance of radiating surfaces, the vertical temperature gradient or the absence of unwanted air streams) are highly desirable. However, in the built and consolidated city, such attention is, to date and according to the plans and projects presented by local administrations, non-existent. Some recent research points out the difference between the subjective perception of the elderly with the real measurements of the urban climate, pointing out the risk of suffering from thermal stress. Many older people can perceive the environment as pleasant despite being in extreme situations (Larriva and Higueras, 2020). The need for microclimatic mitigation and adaptation initiatives in cities is an urgent matter, to improve the lives of the most vulnerable people.

Conclusions

The objective of this report has been to identify the interaction of architecture and urban planning in Madrid with the UHI effect, and to define what influences the experiences of heat in the city. Despite the fact that the UHI effect is widely recognized, both scientifically and socio-politically, and that it is part of the urban imaginary and concerns of citizens, it continues to be an elusive object of study, difficult to identify and delimit. The multiple agents -both human and non-human- that operate in the creation of the UHI make it a diffuse entity. Different scales play a role in the definition of urban temperatures, that go from regional and urban to architectural and individual scale.

We have acknowledged, in this sense, strategies to mitigate the phenomenon that operate at different scales. The most important for the city of Madrid have been pointed out in this report, from thermal insulation to presence of greenery or ventilation schedules.

However, regarding the municipal plans and projects, Madrid's urban planning is not yet prepared for dealing with the overheating phenomenon. This is due to three key aspects:

- High number of non-retrofitted buildings were built up without technical isolation requirements, due to the delay of the first isolation regulation in construction in Spain (1979).
- Energetic rehabilitation, although technically easy to undertake, has been very scarce in recent years, and develops slowly in the present.
- Urban-scale plans for mitigating the effects of overheating are outlined by the administration, but not developed, much less executed.

And, what it is more striking, municipal initiatives tend to afront every overheating-mitigating action from an exclusively top-down perspective, leaving aside many strategies that, from architectural and user scale, could be of great help. The only plan that is directly connected to citizens experiences of heat remains too brief and generic.

The multiplicity of the phenomenon of thermal stress, which is framed within the UHI but which is specified by various parameters (presence of urban greenery, shade, air movement, physical activity, water masses, etc.) makes comparative studies in different situated scenarios necessary. Although some approaches have been made, and some of them have been collected in this document (Tumini, 2013; Larriva and Higueras, 2020), much remains to be investigated. A situated investigation, through personal experiences, in which the variables of architecture, the city and the territory were evaluated could give rise, as a consequence to more detailed architectural practices for dealing with overheating in the built environment.

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