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IDA

IDA: ADVANCED DOCTORAL RESEARCH IN ARCHITECTURE

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FORMATO

Mesas temáticas

Las mesas temáticas son lugares de presentación de las metodologías y las experiencias de jóvenes doctores y de estudiantes de doctorado procedentes de las diferentes universidades. Son gestionadas por los propios estudiantes de doctorado que generan unas conclusiones para ser debatidas y reelaboradas en la sesión plenaria final. Las sesiones se desarrollan de manera simultánea con la presentación de los *papers* seleccionados en la *call*, organizados en cuatro áreas o líneas temáticas:

1. Tecnologías de la Arquitectura
2. Vivienda, Ciudad y Territorio
3. Patrimonio y Rehabilitación
4. Análisis y Proyectos Avanzados

Taller

El workshop del Congreso se orienta hacia el análisis de los problemas y las necesidades de gestión de los Programas de Doctorado con el fin de extraer conclusiones que pueden ser útiles a las Universidades implicadas. En el workshop participan los coordinadores de los programas de Doctorado en Arquitectura y los representantes de los doctorandos. Son temas de debate: las líneas de investigación, las metodologías, las necesidades organizativas de los programas de doctorado, el Doctorado Internacional y el Doctorado Industrial, y el futuro de la investigación doctoral.

Sesiones Plenarias

Las sesiones plenarias se realizan al inicio y al final del Congreso. En la primera sesión de bienvenida e introducción al Congreso se invita a participar a expertos investigadores del panorama nacional e internacional y a los coordinadores de los programas de doctorado. En la segunda sesión plenaria se propone un debate abierto para la reelaboración de las propuestas extraídas del taller y de las mesas temáticas. Sirve también de clausura con la presentación de las conclusiones finales del Congreso IDA_Sevilla 2017.

SCIENTIFIC COMMITTEE

FOREWORD

The Instituto Universitario de Arquitectura y Ciencias de la Construcción (IUACC), in collaboration with the Escuela Técnica Superior de Arquitectura (ETSAS) and the Escuela Internacional de Doctorado (EIDUS) of the University of Seville are pleased to welcome the heads of research from both Spanish and overseas universities, consolidated researchers and young doctoral researchers to the First International Congress of Doctorates in Architecture IDA Sevilla, from 27th to 28th November 2017.

The **IDA_Sevilla 2017** Congress offers a general perspective of doctoral studies in the field of Architecture and its related disciplines: urban planning, heritage, landscape, construction technologies and sustainability. In the new context generated after the elimination of the doctoral programs prior to RD 99/2011, it is necessary to carry out an analysis of the complex panorama that the former programs and the new doctoral programs have drawn up, in order to know in detail both what has been achieved so far, as well as the challenges of the future of advanced doctoral research in Spain, in the European and international context.

The startling changes that are taking place in our society call for a vision of research that is not compartmentalised into traditional disciplines or areas of knowledge. Doctoral research in Architecture must adapt to changes in society and to the sustainable productive needs of territory.

The congress will take place at the Escuela Técnica Superior de Arquitectura de Sevilla, organised in four simultaneous thematic tables, a workshop on the administration of doctoral programs and two plenary sessions.

The **thematic tables** are aimed at young doctors and doctoral students of the different participating universities who will present their experiences and methods of their research - in development or recently concluded. The participation in the thematic tables is carried out through the selection procedure with blind peer review established in the call for papers and through express invitations to the debate. The almost 70 communications have been structured in four thematic areas representative of the PhD programs in Architecture.

The **open workshop** will be held in two sessions with the participation of the coordinators of each of the collaborating programs of the Congress, and professors with extensive doctoral experience. Its objectives are multiple: to discuss the experiences undertaken in the different universities, exchange ideas about the approaches and models applied, address the challenges of internationalization and management, launch the new Industrial Doctorate with companies and public agencies, and so on.

There are two **plenary sessions**: one, a plenary session of introduction to the congress, with the participation of coordinators of national and foreign doctoral programs; and a closing plenary session, with an open debate for the going-over of the conclusions drawn from the thematic tables and the workshop, and the presentation of final conclusions.

We thank the Escuela Internacional de Doctorado of the University of Seville, and the Escuela Técnica Superior de Arquitectura de Sevilla for the support they have provided for the holding of this meeting, which contributes so much to the clarification of the future of doctoral studies in Spanish universities in the face of the great challenge of internationalization and the continuous improvement of the quality of research in Architecture. We also thank those responsible for the participating Doctoral Programs, the Architecture library of the US and all the participants and attendees.

Antonio Tejedor Cabrera
Marta Molina Huelva

Conference Chairpersons IDA_Sevilla 2017
Instituto Universitario de Arquitectura y Ciencias de la Construcción IUACC

PRÓLOGO

El Instituto Universitario de Arquitectura y Ciencias de la Construcción (IUACC), con la colaboración de la Escuela Técnica Superior de Arquitectura (ETSAS) y la Escuela Internacional de Doctorado (EIDUS) de la Universidad de Sevilla, se complacen en recibir a los responsables de investigación de universidades españolas y extranjeras, a los investigadores consolidados y a los jóvenes investigadores de doctorado en el I CONGRESO INTERNACIONAL DE DOCTORADOS EN ARQUITECTURA IDA_Sevilla, del 27 al 28 de noviembre de 2017.

El congreso **IDA_Sevilla 2017** ofrece una perspectiva general de los estudios de doctorado en el campo de la Arquitectura y sus disciplinas afines: urbanística, patrimonio, paisaje, tecnologías de la construcción y sostenibilidad. En el nuevo contexto generado tras la extinción de los programas doctorales anteriores al RD 99/2011 es necesario realizar un análisis del complejo panorama que han construido los programas extintos y los nuevos programas de doctorado, con el objeto de conocer con detalle tanto lo conseguido hasta ahora como los retos que depara el futuro de la investigación doctoral avanzada en España, en el contexto europeo e internacional.

Los vertiginosos cambios que se están produciendo en nuestra sociedad reclaman una visión de la investigación no compartimentada en disciplinas o áreas de conocimiento tradicionales. La investigación doctoral en Arquitectura debe adaptarse a los cambios de la sociedad y a las necesidades productivas sostenibles en el territorio.

El congreso se celebra en la Escuela Técnica Superior de Arquitectura de Sevilla organizado en cuatro mesas temáticas simultáneas, un taller sobre la gestión de los programas de doctorado y dos sesiones plenarias.

Las **mesas temáticas** están dirigidas a los jóvenes doctores y a estudiantes de doctorado de las diferentes universidades participantes que exponen sus experiencias y métodos sobre las investigaciones en desarrollo o recientemente concluidas. La participación en las mesas temáticas se realiza por el procedimiento de selección con revisión por pares ciegos establecido en la *call for papers* y por medio de invitaciones expresas al debate. Las casi 70 comunicaciones se han estructurado en cuatro áreas temáticas representativas de los programas de doctorado en Arquitectura.

El **taller** de puesta en común se realiza en dos sesiones con la participación de los coordinadores de cada uno de los programas colaboradores del Congreso y de profesores con amplia experiencia doctoral. Sus objetivos son múltiples: debatir sobre las experiencias desarrolladas en las distintas universidades, intercambiar ideas sobre los enfoques y los modelos aplicados, abordar los retos de internacionalización y de gestión, poner en marcha el nuevo Doctorado Industrial con empresas y agencias públicas, etc.

Las **sesiones plenarias** son dos: una sesión plenaria de introducción al congreso, con la intervención de coordinadores de programas de doctorado nacionales y extranjeros; y una sesión plenaria de clausura, con un debate abierto para la reelaboración de las conclusiones extraídas de las mesas temáticas y del workshop y la presentación de las conclusiones finales.

Agradecemos a la Escuela Internacional de Doctorado de la Universidad de Sevilla y a la Escuela Técnica Superior de Arquitectura de Sevilla el apoyo que han proporcionado para la realización de este encuentro que tanto contribuye a clarificar el futuro de los estudios doctorales en las universidades españolas ante el gran reto de la internacionalización y la continua mejora de la calidad de la investigación en Arquitectura. Damos los gracias también a los responsables de los Programas de Doctorado participantes, a la Biblioteca de Arquitectura de la US y a todos los participantes y asistentes.

Antonio Tejedor Cabrera
Marta Molina Huelva

Directores Congreso IDA_Sevilla 2017
Instituto Universitario de Arquitectura y Ciencias de la Construcción IUACC

OBJECTIVES

1. Analyze the research lines of the various programs and build a map of doctoral research in Spain with the support of coordinators, tutors / thesis supervisors, doctoral students and young doctors in the disciplines related to Architecture and their related areas.

2. To know the status of doctoral theses in progress or defended in the last three years, selected by means of a call with blind peer evaluation of the doctoral programs participating in the congress.

3. Discuss the structure and university management of doctoral programs in relation to employment challenges, collaboration with the productive sector and national research programs.

4. Exchange experiences with other international doctoral research programs on international mobility management, theses with international mention, co-supervised theses, theses with industrial mentions, etc.

5. No less important, consolidate a national and international network of Doctoral Programs related to Architecture, Urban Planning, Heritage, Landscape, Technologies and related disciplines.

ADVANCED DOCTORAL RESEARCH

LT1 ARCHITECTURE TECHNOLOGIES

LT2 HOUSING, CITY AND TERRITORY

LT3 HERITAGE AND REHABILITATION

LT4 ANALYSIS AND ADVANCED PROJECTS

FORMAT

Thematic tables

The thematic tables are places to present the methodologies and experiences of young doctors and doctoral students from different universities. They are managed by the doctorate students themselves, who generate conclusions to be debated and reworked in the final plenary session. The sessions are developed simultaneously with the presentation of the papers selected in the call, organized in four areas or thematic lines:

1. Architectural technologies
2. Housing, city and territory
3. Heritage and Rehabilitation
4. Analysis and advanced projects

Workshop

The workshop of the Congress is oriented towards the analysis of the problems and management needs of the Doctorate Programs, with the objective of arriving at conclusions that may be useful to the Universities involved. The coordinators of the Doctorate in Architecture programs and the doctoral students' representatives will participate in the workshop. The following are topics for debate: lines of research, methodologies, organizational needs of the doctoral programs, the International Doctorate and the Industrial Doctorate, and the future of doctoral research.

Plenary Sessions

The plenary sessions are held at the beginning and end of the Congress. In the first session of welcome and introduction to the Congress, researchers from the national and international scene and the coordinators of the doctorate programs are invited to participate. In the second plenary session an open debate is proposed for the going over of the proposals drawn from the workshop and the thematic tables. It also serves as a closing ceremony with the presentation of the final conclusions of the 2017 IDA_Sevilla Congress.

Beams were tested in bending, according to UNE-EN 408 (2011) (Fig.6), and the effects of GFRP reinforcements in the MOE, ultimate strength (MOR) and improvement in the dispersion of results were measured and analyzed. The failure modes of each beam were also observed.

Fig. 6 Duo beams test according to UNE EN-408.

The results of these tests on reinforced Populus beams are shown in Figure 7, with a significant improvement with increments in the moduli of elasticity of 10% for GFRP reinforcements of 1200 gr / m2 and of around 15% for GFRP reinforcements of 2400 gr / m2.

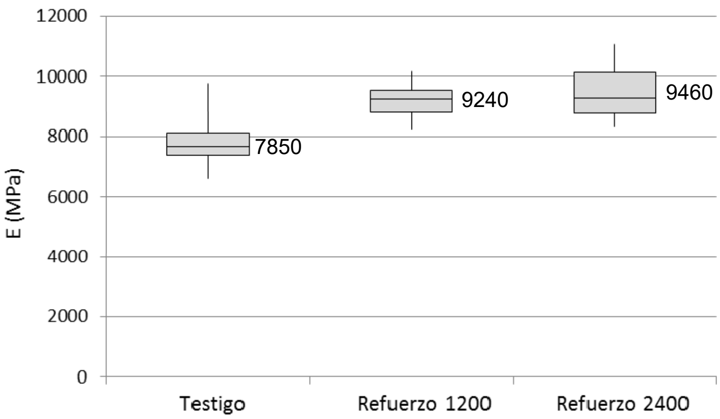

Fig. 7 Box and whiskers graph with the modulus of elasticity of poplar duo beams.

At the present time only the previous data analyzes of the poplar duo beams are available, and the bending test of the Pinaster beams is scheduled for close dates.

3.3. Creep tests

In order to study the long-term behavior of the reinforced duo beams, in relation to unreinforced ones, a long-term test has been set up, according to UNE-EN 380 (1998), with a total load of 10 kN, which represents approximately 50% of ultimate load of the beams. The ambient conditions of the laboratory remain nominally constant, 20 ± 2ºC; 65 ± 5% humidity in air, corresponding to a hygroscopic balance of 12% HR in the wood (Kollman 1959).

The load is applied by means of the filling and filling of individual tanks (Figure 8), single wall polyethylene (PE), with a useful capacity of 1000 liters and dimensions of approximately 1650x720x1260 mm, with upper filling nozzles and lower emptying device, with locking key. The support of the tanks on the beams is made with an intermediate resistant platform, which allows to apply the load on the beams on two points, following the support distances proposed by UNE-EN 408 (2011).

OBJETIVOS

1. Analizar las líneas de investigación de los diversos programas y construir el mapa de la investigación doctoral en España con el apoyo de los coordinadores, los tutores/directores de tesis, los doctorandos y los jóvenes doctores en las disciplinas relacionadas con la Arquitectura y sus áreas afines.

2. Conocer el estado de las tesis doctorales en marcha o defendidas en los últimos tres años, seleccionadas por medio de una *call* con evaluadores por pares ciegos de los programas de doctorado participantes en el congreso.

3. Debatir sobre la estructura y la gestión universitaria de los programas de doctorado en relación con los retos de empleo, colaboración con el sector productivo y los programas nacionales de investigación.

4. Intercambiar experiencias con otros programas de investigación doctoral a escala internacional sobre gestión de la movilidad internacional, tesis con mención internacional, tesis en cotutela, tesis con mención industrial, etc.

5. No menos importante, consolidar una red nacional e internacional de Programas de Doctorado relacionados con la Arquitectura, la Urbanística, el Patrimonio, el Paisaje, las Tecnologías y sus disciplinas afines.

INVESTIGACIÓN DOCTORAL AVANZADA SEVILLA

LT1 TECNOLOGÍAS DE LA ARQUITECTURA

LT2 VIVIENDA, CIUDAD Y TERRITORIO

LT3 PATRIMONIO Y REHABILITACIÓN

LT4 ANÁLISIS Y PROYECTOS AVANZADOS

IDA SEVILLA

LT1

TECNOLOGÍAS DE
LA ARQUITECTURA

ARCHITECTURE TECHNOLOGIES / TECNOLOGÍAS DE LA ARQUITECTURA

THERMODYNAMICS OF MEDITERRANEAN COURTYARDS: QUANTIFICATION AND APPLICATIONS IN ECO-EFFICIENT ARCHITECTURAL DESIGN

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Abstract: This work studies the use of Mediterranean courtyard in architecture as a passive system of saving energy, through the detailed understanding of its thermodynamic behavior. Its historical importance in architecture is studied, proposing to explain its origin and longevity, an approach that emphasises the physical qualities and objective advantages that the courtyards demonstrate. We describe the current state of technical knowledge that we have about its purpose in architecture, whilst noting that the current programs of energy qualification discourage the use of the courtyard by not considering the existence of a microclimate inside. Later, the description and understanding of the physical phenomena that create the microclimatic behavior are shown in relation to their geometric characteristics. This is done both at a theoretical level with the study of several designs typologies, and at the experimental level, with the monitoring and study of the design of real courtyards.

Key words: Microclimate, CFD, Mediterranean climate, Courtyard, Eco-efficiency.

1. Objetives

To understand and quantify both the microclimate of the courtyard and its influence on the eco-efficiency of buildings. For this, computerized simulations are developed using original code capable of calculating the courtyard temperature for a given climate and architecture.

2. Introduction

The importance of the courtyard in Mediterranean architecture is evidenced by being the most representative space of the house in the cities of these regions, from the dawn of civilization (Capitel 2005, Díaz Recasens 1997, Pérez de Lama 1996). The Roman house and the Muslim house are clear exponents of this with the Mediterranean arch as it has been shown. The prevalence or disappearance of the courtyard has been analyzed in the same cultural environment but in a different climate. Figure 1 compares Santiago de Compostela in northern Spain, which has a colder climate, and Seville, a city in the south that has a warmer climate. In Santiago the courtyards are scarce, however, in Seville they are a significant part of the urban structure.

a b

Fig. 1 Comparison between the urban structure of Santiago de Compostela (a) and Seville (b)

On the other hand, there are courtyards that organize the spaces of the houses in a very similar way to those of the Mediterranean in different and distant regions of the earth that share warm climates. There are courtyards in remote regions of China and pre-Columbian America (Carballo 2016) where cultural continuity has not been possible. Therefore, that the courtyard is more typical of warm or warm-temperate climates and less of cold climates indicates that it is a climatic adaptation of the building. It is proposed as a hypothesis that the existence of a microclimate in these spaces with cooler air than the exterior, helps to moderate the temperature of the building.

3. Scientific framework

However, when studying the scientific and technical framework on energy-sustainable construction, we can see the serious problems of understanding the strategy of the yard. In most of the international reference works studied there was no mention of the courtyard, nor referrals to warm climates. When it appears, it does so partially, describing only its ventilation qualities and rarely its microclimatic properties (Energy Research Group of University College Dublin 2014). National research papers, give this issue a greater degree of attention and study to these qualities, although they cannot be quantified (Neila González 2004). A reasonable cause of lack of climatic-cultural familiarity is established with the courtyard solution, which makes its understanding more difficult as a bioclimatic strategy in northern climates. But also the great difficulties of the scientific and quantitative description of the phenomenon, contribute to its lack of technical consideration.

In this sense, it is confirmed that both the most extensive energy efficiency software and those that determine the obligatory qualification of the energy performance of the buildings in countries like Spain, do not consider the existence of a real microclimate, different from the outside, inside the courtyards which can contribute to energy savings in buildings. The energy paradigm, assumed for any climate, is to make buildings as compact as possible, with the lowest coefficient of form, through regulations such as the CTE (Díaz Guirado & Allepuz Pedreño 2016), criteria of public tenders and engineering prescriptions, make the integration of courtyards all the more difficult in contemporary designs.

In recent years, new approaches to computational fluid dynamics (CFD) research (Murakami 2006) (Kubota et al. 2017; Micallef et al. 2016; Almhafdy et al. 2015; Padilla-Marcos et al. 2015; Bajunid et al. 2013; Al-Masri & Abu-Hijleh 2012; Moonen et al. 2011; Muhaisen 2006; Rajapaksha et al. 2003) as well as the different approaches to the comfort factor contributing to the field of adaptive thermal comfort (Nicol et al., 2012), have opened up better prospects for the consideration of courtyards in naturally ventilated buildings. Therefore, the need to scientifically establish the way in which courtyards are really effective climate adaptations and to properly quantify their behavior is made clear.

Likewise, it is hypothesized that there is a "natural" adaptation of the characteristics of the courtyard to each climate. Thus, it can be seen that some dimensional characteristics of the courtyards are related to the climate where they are located. This allows a link to be established between its architectural form and its microclimatic behavior. It is architecture that creates and conditions the microclimate of the courtyard. Different geometries and elements (vegetation, water, shade) defined by the architecture modify the thermodynamic behavior of the courtyard. In particular, after a study of different types of historical courtyards, it is observed that in warmer regions, the courtyards tend to be deeper (depth as the ratio between height and width $P = h / a$) than in cold ones Table 1). However, in colder regions the courtyards do not exist as we have seen or when they do, they are usually larger and of smaller depths (wider) as reflected in figure 2.

Tabla 1. Depth of historical courtyards.

CLIMAS	TAMAÑOS	PROFUNDIDAD P						
			< 0,2	0,2-0,4	0,5-0,9	1-1,9	2-3	>3
CLIMAS MEDITERRÁNEOS	PEQUEÑA ESCALA	Mesopotamia					■	
		Antiguo Egipto			■	■	■	
		Antigua Grecia			■			
		Antigua Roma					■	
		Islam					■	■
		Andalucía s.XVII-XIX					■	■
		Modernidad			■	■		
	GRAN ESCALA	Antigua Roma				■		
		Islam-Mudéjar				■		
		Renacimiento				■		
		Andalucía s.XVII-XIX				■		
		Manzanas de ensanche		■	■	■		
CLIMAS FRÍOS	PEQUEÑA ESCALA	Poco frecuentes						
	GRAN ESCALA	Medieval gótico	■	■				
		Ciudades centroeuropeas	■					

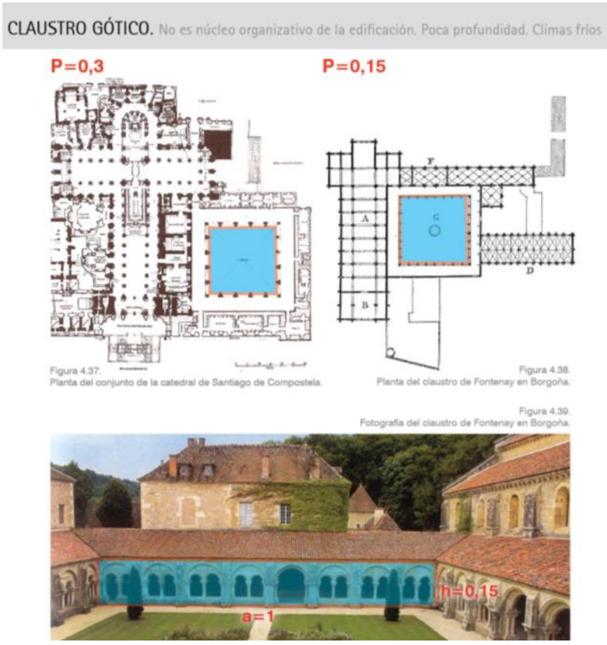


Fig. 2 Courtyard poco profundo típico de clima frío.

4. Thermodynamics of the courtyard

The specific thermodynamic characteristics of the courtyards show, the relationship between the geometry of the courtyards and their different thermodynamic behavior. Specifically, the thesis studied how the primary physical phenomena that affect the microclimate of the courtyard´s, stratification, convection and flow patterns, are modified by the depth. The existence of thermal sinks such as shaded walls or the presence of water and vegetation (evaporative cooling) complete the understanding of the phenomenon. At greater depth and warmer climate, the microclimate is more intense, allowing a greater differentiation of the temperature of the courtyard, compared to the exterior. This explains the relationship between the depth of the courtyard and the warmer climate it is exposed to and justifies that the courtyards are more typical of warm climates than of cold ones. As a consequence of the fluid dynamic nature of the phenomenon, this relationship is not linear.

Precisely because of the complexity of the interaction of all these factors in a context of fluid dynamics, the limitations of purely analytical studies that try to describe these phenomena through simplified formulations are evident. To integrate the complexity of this behavior it is necessary to use simulations using specific numerical models in the context of the scientific field of computational fluid dynamics. For this reason, a simulation method has been developed using a code based on the Freefem ++ free code finite element calculator with the objective of simulating the thermodynamics of the courtyard and quantifying the temperature difference with the exterior. The thesis develops a method, in which the tools of architectural design (CAD, BIM, Sketchup ...) are integrated with the numerical simulations. These numerical models have been tested first with simple geometries confirming that they reproduce experimental results obtained in previous research (De La Flor & Domínguez 2004). They have also allowed us to better understand the relationships between the geometry of the courtyard and its thermodynamic behavior (fig. 3), which allow us to better explain why the microclimate is more intense in deeper courtyards. As it gets deeper the studied phenomena, especially stratification, increase in intensity caused by the greater isolation of the air of the courtyard with respect to the external air. The study is carried out on types courtyards for external conditions that do not represent the complexity of the real summer or winter conditions but give notions of their thermodynamic behavior to each isolated phenomenon.

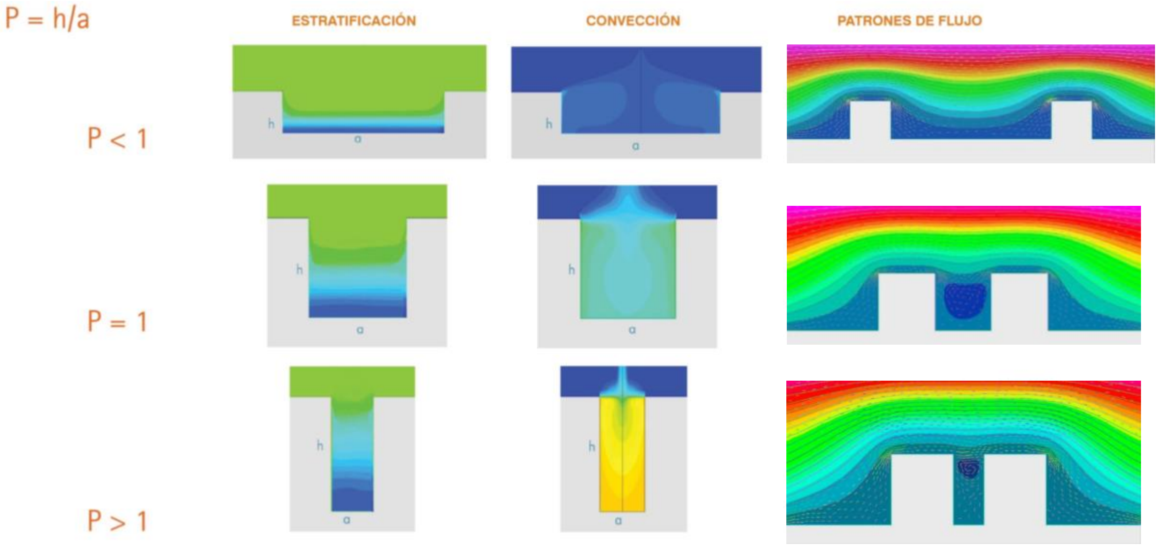


Fig. 3 Depth and thermodynamic behavior of the air in the courtyard. For stratification and convection the colors represent temperatures and for the flow patterns the colors are different air velocities (the values are nominal not realistic so no scales are represented)

5. Study of real courtyards.

An important piece of the thesis consisted of the monitoring of real courtyards with two objectives. On the one hand, we can verify directly the existence of a microclimate in the courtyards to dispel doubts that might still exist; precisely measuring the intensity of the phenomenon as the difference between temperature inside the courtyard and outside. On the other hand, to obtain a reliable data source with respect to real buildings that allows us to test the methods of developed simulations, testing if our models are able to calculate the temperature inside the courtyard from the external conditions and the concrete architecture of the building.
We are interested only in monitoring the air temperature (dry bulb) so we measure temperatures in the shade discarding the effects of radiation. This air, hidden from the radiation and not directly affected by it, is the one that will end up entering the building, thus conditioning the interior environment with its temperature. On the other hand, it also takes into account the direct comfort of the people in the yard. The adaptive thermal comfort approach (which we will delve into at the end of the work), indicates that the microclimate of the courtyard will be in the shadow zone, never under the sun. The human in spaces with great thermal contrasts, adapts. Always looking for the zone of greatest comfort at each time of day, in the case of a courtyard and in our climate that is the shaded area. Therefore, to determine the comfort by looking in that space and recording a single temperature based on means of extreme temperatures of different areas and times does not offer relevant information. It is found that this is what the most widespread nodal calculation programs that calculate the comfort and general energy balance of buildings do. This impairs the fair evaluation of the microclimate of the courtyards.
The monitoring campaign of courtyards in three Andalusian cities, Córdoba, Seville and Málaga (Figure 4), shows the existence of a pattern of temperature differences between the interior and exterior, evolving during the hours of the day, revealing the unambiguous existence of a microclimate inside the courtyard.

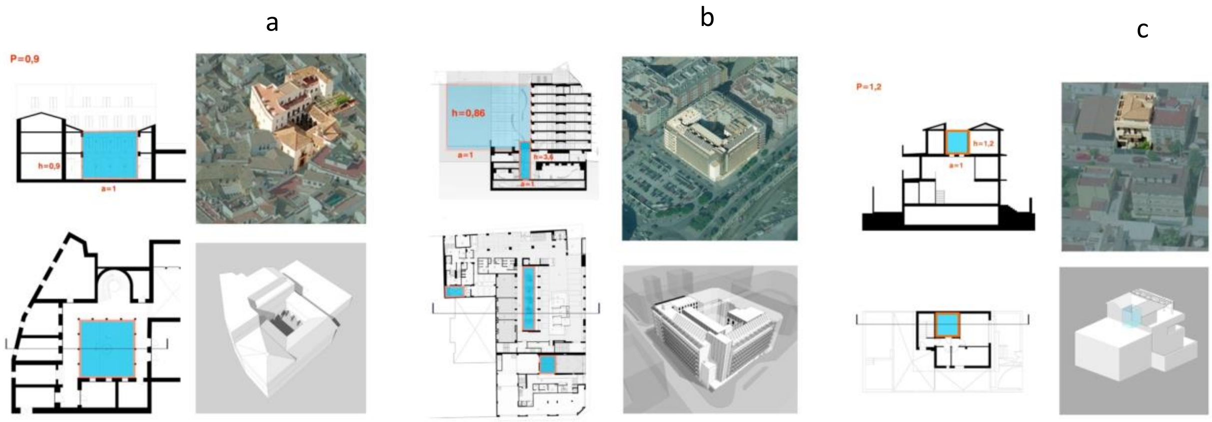


Fig. 4 Courtyards studied in Córdoba (a), Málaga (b) and Seville (c).

In each season different intensities of microclimate have been detected, that is to say, greater or smaller differences between the temperature in the courtyard and outside. What has been experimentally concluded is that most of these differences are due to different external conditions. When outdoor temperatures are high, the microclimate of the courtyard is especially intense, reaching temperature differentials between the interior and exterior of more than 8 ºC (fig 5). When the temperatures are lower, the differences between the courtyard and the outside diminish even becoming negative, which implies that when the temperature falls at night, the temperatures in the courtyard are sometimes higher than the exterior temperatures (fig 6).

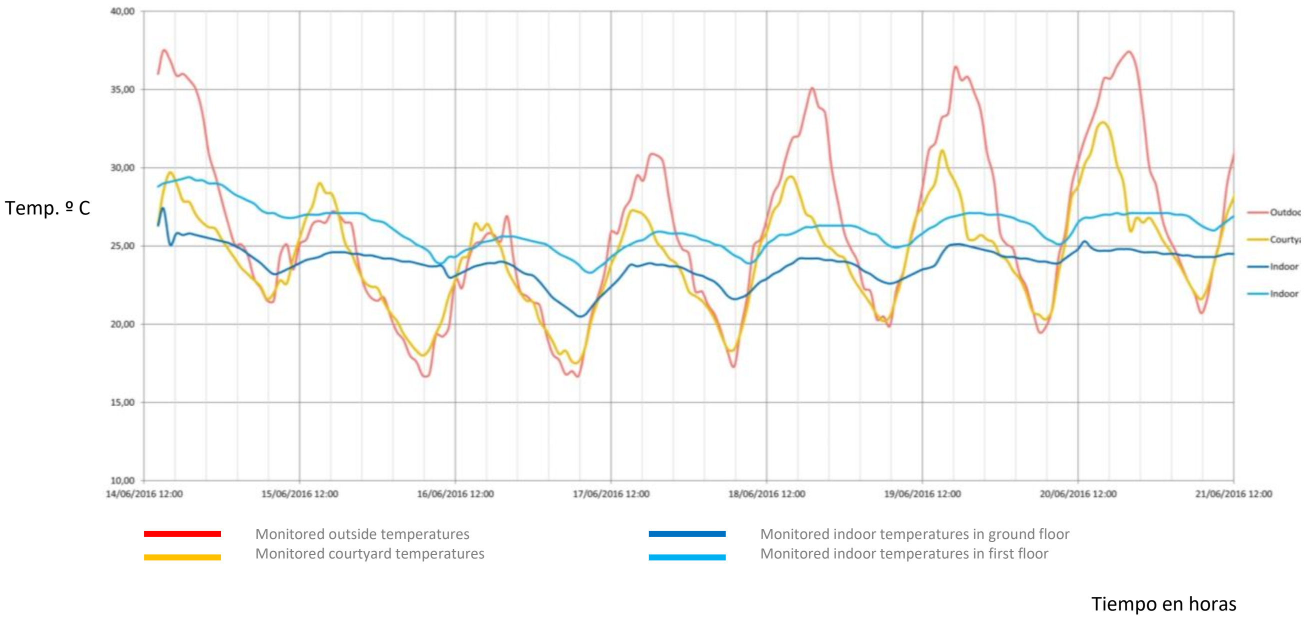


Fig. 5 Evolution of temperatures inside the courtyard of Cordoba, outside and inside the building.

The comparative study of the evolution curves of the outside temperatures of the courtyard and of the interior of the building has allowed several conclusions to be drawn:

The microclimate of the courtyard is not explained by the contribution of warmer air from the interior of the building. This would imply a neutral final balance and the poor efficiency of the courtyard microclimate on the energy performance of the building. The analysis of the phases of the thermal waves shows this. The waves of the thermal curves of the courtyard are only in phase with the exterior climate not with the interior. The explanation of the microclimate as a simple mixture of interior and exterior conditions is not exact. The microclimate of the courtyards is explained by thermodynamic phenomena derived mainly from the exterior conditions and the geometry of the courtyard and not so much from the interior temperatures of the building. That is to say, despite all the energetic exchanges between the interior of the building and the courtyard through the enclosures and the openings, the air temperature of the courtyard is not always that of the interior of the building. The existence of thermal sinks in the courtyard as cooler walls (thermal inertia) or evaporative cooling due to the presence of water or vegetation is a phenomenon that can contribute to the creation of the microclimate, but importantly not the contribution of air from inside the building. In fact, the airflow in the courtyards studied usually flows from the courtyards to the interior of the buildings. Therefore, the effect of the courtyard microclimate on the overall energy balance of the building is positive.

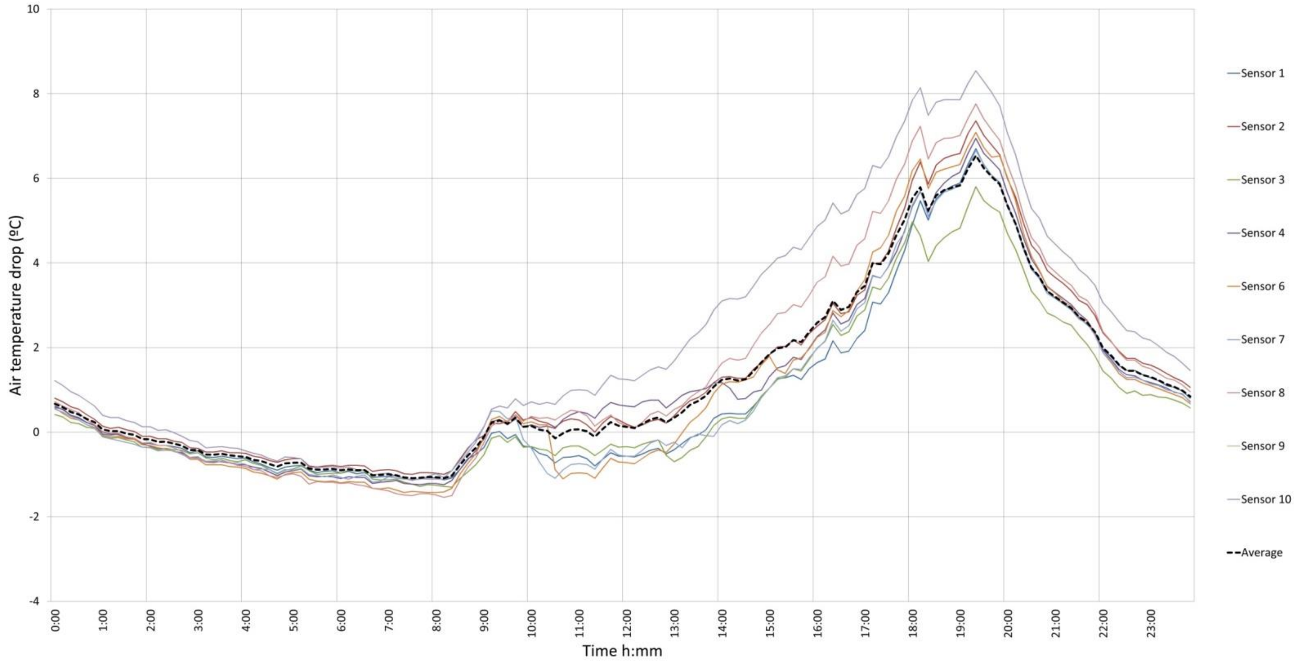


Fig. 6 Weekly average of the hourly differences between the courtyard temperature and the outside temperature.

On the other hand, it is verified that the interior temperatures of naturally ventilated courtyard buildings are more related to courtyard temperatures than to exterior temperatures. Changes in exterior temperatures do not produce a rapid change in the evolution of courtyard temperatures or in the evolution of the building's interior temperatures. Therefore, the interior temperature in a Mediterranean building with a courtyard depends more on the temperature of the courtyard than on the exterior temperature. It is logical if we consider that naturally ventilated buildings, such as the one studied in Cordoba, take in most of their external air through the courtyard. This is because it is here that they are most open to the outside. In addition, this opening mainly occurs on the ground floor, where the microclimate of the courtyard is most intense because the stratification makes the air located at lower levels cooler.

On the other hand, in the fieldwork it is observed that the microclimate of the courtyard has greater intensity when the external temperatures are high (greater than 25º C). When they are low, the temperature of the courtyard is equal to the outside. Therefore, it is inferred that the courtyard has a neutral behavior in winter with similar temperatures to the exterior.

6. Simulations of real yards previously monitored.

Para terminar de analizar y entender estos comportamientos, se han realizado simulaciones por ordenador usando, en primer lugar, programas comerciales de uso extendido como el DesignBuilder (fig.7). Se ha modelizado en este programa el edificio estudiado en Córdoba, introduciendo como clima exterior las temperaturas reales monitorizadas en vez de las que por defecto trae el programa en su archivo climático. Se trataba de observar con mayor precisión si, para un edificio naturalmente ventilado con courtyard como el estudiado, el programa reproduce las temperaturas interiores reales monitorizadas. Se ha comprobado que las temperaturas interiores calculadas por programas comerciales como el usado son muy superiores a las reales monitorizadas y similares a las exteriores en la cubierta del edificio. La necesidad de abarcar en esta tesis diferentes aspectos del problema para obtener un entendimiento global del mismo, limita la posibilidad de realizar muchas más simulaciones sobre los courtyards monitorizados en distintas campañas. Esto, sin duda permitirían un mejor y más detallado establecimiento de los hallazgos. Pero se considera suficientemente demostrado que programas como el usado no calculan correctamente el comportamiento termodinámico de edificios naturalmente ventilados con courtyard. Esto es lógico si tenemos en cuenta que no consideran la existencia de un microclima dentro del mismo. Para estos programas la temperatura en el courtyard es exactamente igual que la temperatura exterior en cubierta.

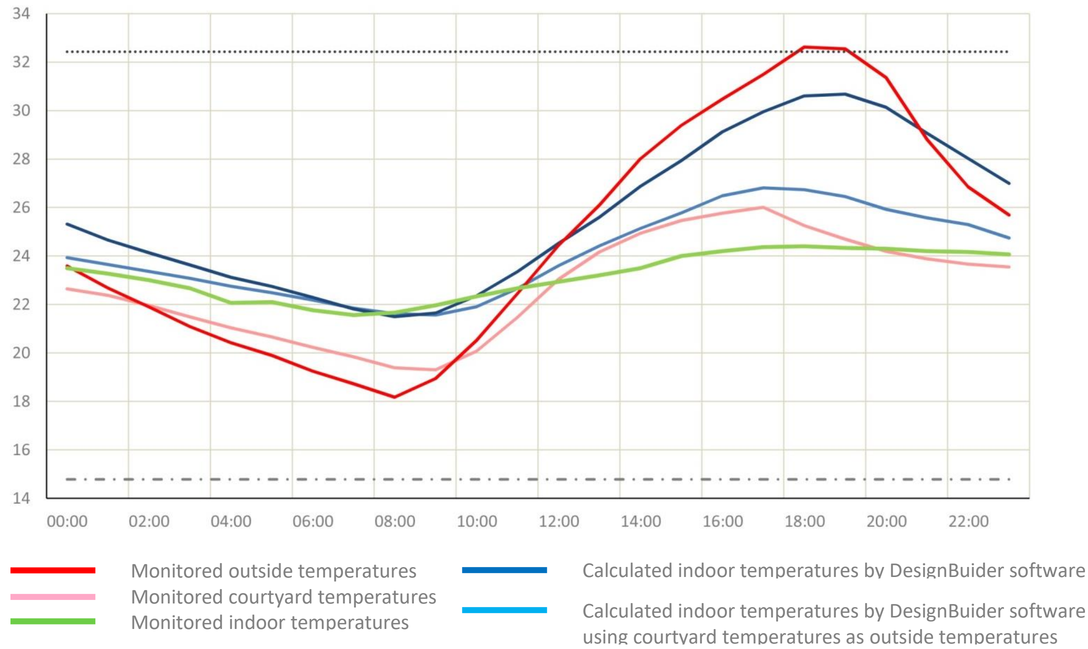


Fig. 7 Calculation of interior temperatures of the Cordoba building done with DesignBuilder.

Assuming the limitations of the program on this point, but understanding that the overall energy balance of the buildings is realised with more fidelity in other designs without courtyard, another simulation is carried out in which the climatic file is manipulated to introduce the monitored temperatures of the real courtyard. The indoor temperatures now calculated by the program closely resemble the actual temperatures monitored inside the building. This has two important implications.
The actual influence of the microclimate temperatures of the courtyard on the interior temperatures of naturally ventilated buildings is demonstrated. On the other hand, it points out the way to evaluate the energy performance of the courtyard in the design of new buildings. Developing a method to calculate the temperatures produced by the courtyard microclimate, we could introduce them as we have done in commercial energy balance programs and calculate with more precision the energy behavior of buildings with courtyard.

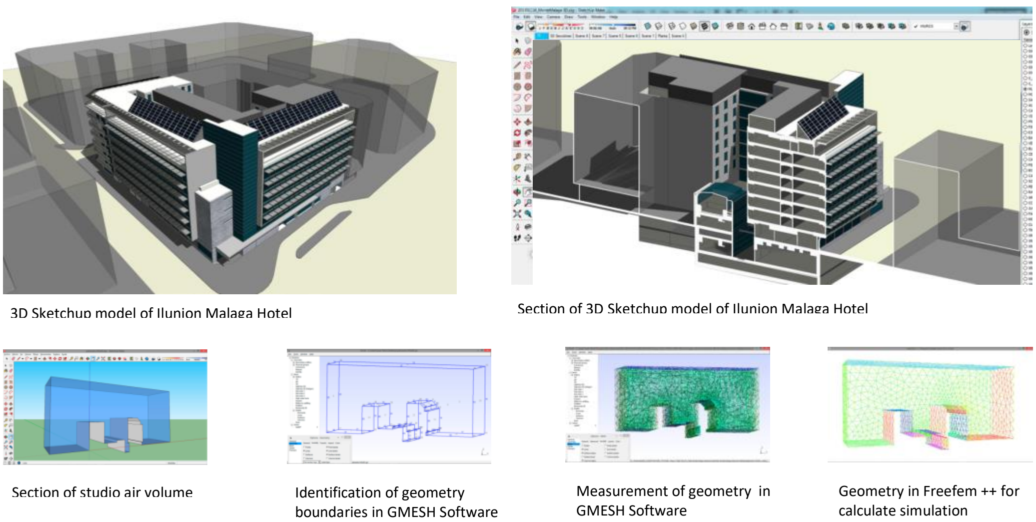


Fig. 8 Process of generation of geometry and meshing for simulation.

Therefore, the simulation method developed to calculate the temperatures due to the microclimate of the courtyard is now used. The building of the Hotel Ilunion Málaga is modeled for its special geometric complexity and for representing a contemporary example of the use of the courtyard strategy (fig.8). Not only does it allow for the use of the microclimate of the courtyard passively functioning as a natural ventilation system, but it also integrates the active taking air from the courtyard for the general air conditioning system. This shows another more technical possibility in the design and use of the yard and makes more obvious, if necessary, the need for the quantification of its behavior.

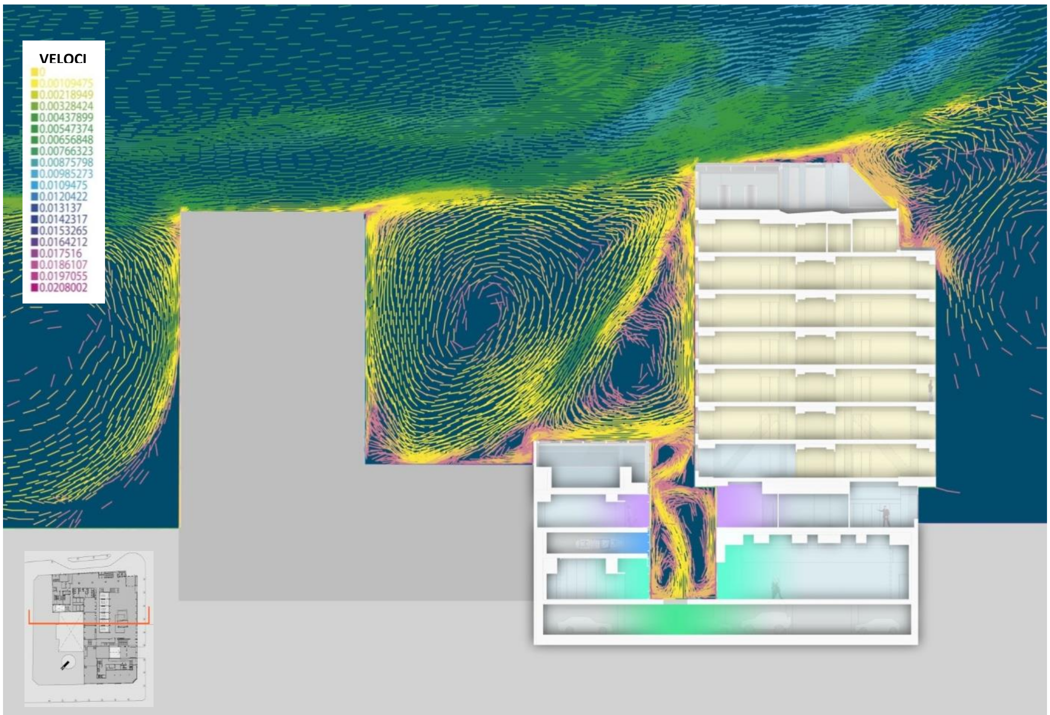


Fig. 9 Flow patterns of wind-induced currents for this geometry (Rojas-Fernández et al., 2012).

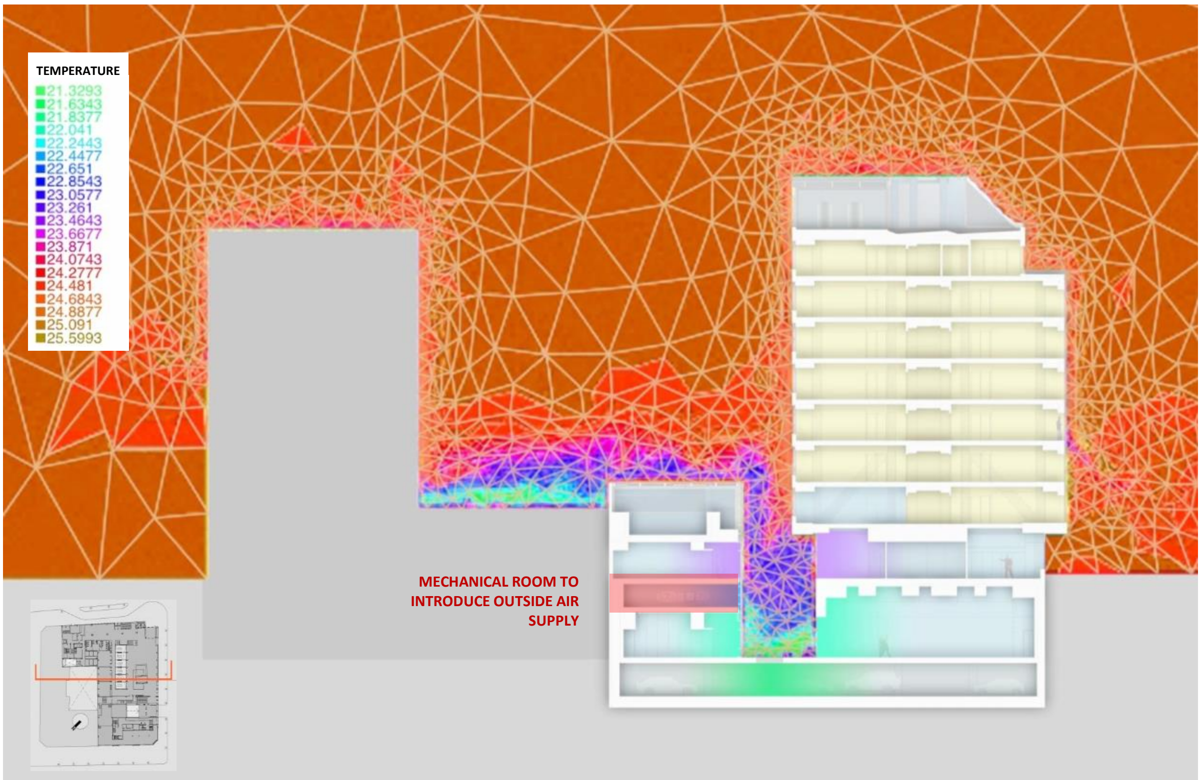


Fig. 10 Simulation of the distribution of temperatures in the courtyard (Rojas-Fernández et al., 2012).

As mentioned above, the reduction of the study to this example is justified by the more general objectives of the thesis. But it would be necessary to have a monographic work with a sufficient number of simulations compared to their corresponding monitoring that would finish describing in detail the scope and limitations of the proposed simulations.

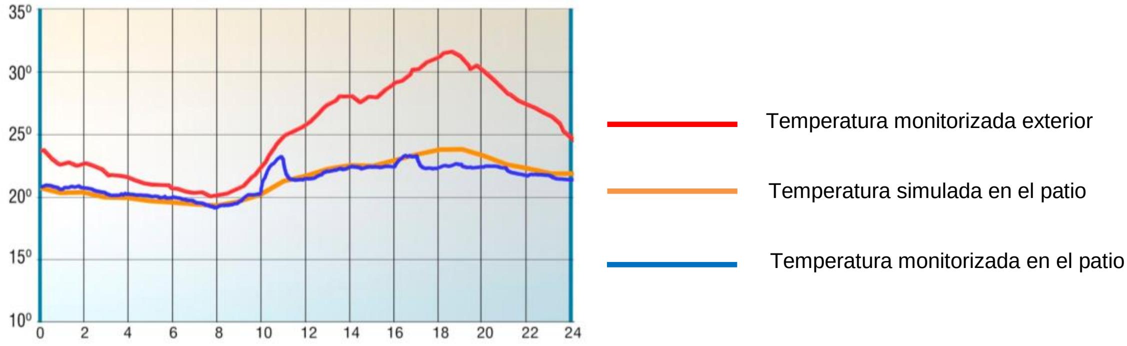
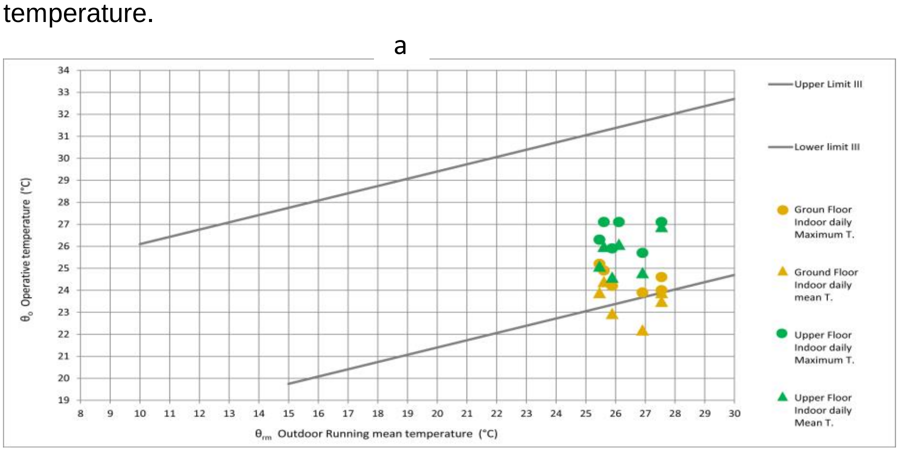


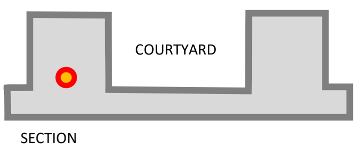
Fig. 11 Comparison between the temperature curve in the simulated and monitored courtyard (Rojas-Fernández et al., 2012).

7. Contribution of the courtyard to adaptive comfort.

Finally we study the effect of the bioclimatic strategy of the courtyard on human comfort. It is analyzed in the comfort inside of buildings with courtyards, and in the courtyard itself. It is noteworthy to emphasise that in order to assess comfort in the courtyards, the methodologies applicable to exterior spaces are not used, as would seem logical, instead those used are designed to assess interior comfort. The reason for this is as we have seen, courtyards are not entirely exterior or entirely interior spaces, but a complex interaction of both. If we adopt the comfort criteria for interior spaces to courtyards, we will be on the side of safety because these criteria are more restrictive than those used for exteriors. On the other hand (as I was able to study at the University of Kent) the best external comfort ratings are based on extensive well-standardised surveys made to the casual user of those spaces. The Mediterranean courtyards studied are usually private spaces whose users are neither casual nor statistically neutral. It would be necessary to introduce into these spaces "fictitious users" that we would have to select in some way. All this would be a bias to the study that would greatly reduce the objectivity and value of the study. Therefore a more neutral procedure is chosen that takes advantage of the objective monitoring carried out on the microclimate of the courtyards to assess their degree of comfort.

The new approach to adaptive comfort is adopted because it is the best approximation we have to the phenomenon. This is demonstrated by its adoption in the new standards of comfort both European (EN 15251) and American (ASHRAE 55). The key factor is to understand that comfort is a human parameter and therefore complex as it pertains to physiology and psychology. The traditional simplified physical formulations based on equations of the body's thermal balance with its surroundings, fail to correctly define the comfort parameter. Only through extensive survey campaigns has it been possible to determine that people find comfort more easily in spaces that have zonal and temporal temperature variations, always related or coupled with the outside temperature. The interior comfort depends on the outside temperature and the adaptation of the person to the climate, the culture and the building where you are. In this context, the well-being and comfort of the human being depends very much on maintaining contact with the evolution of the environment and the outside temperature.





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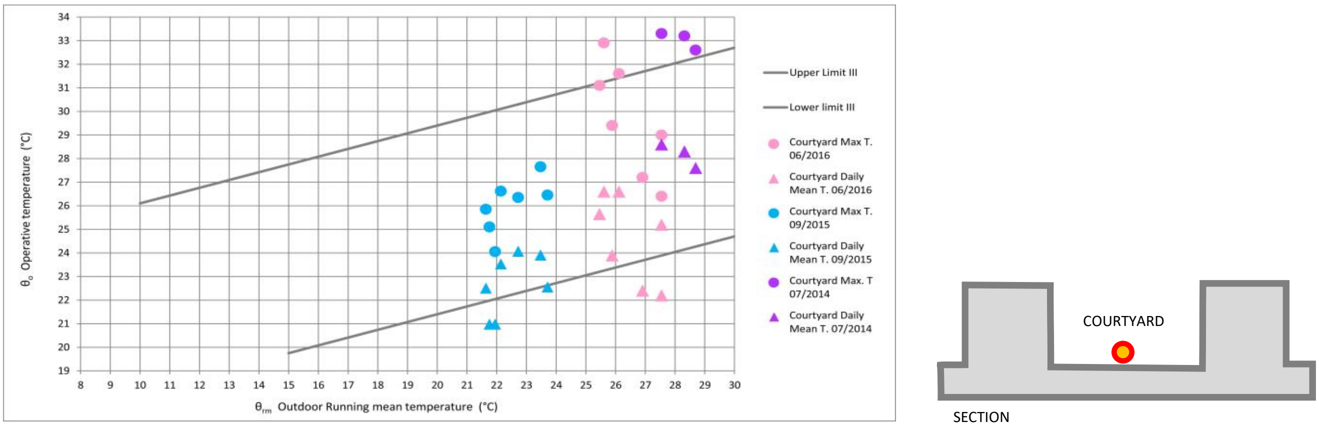

Fig. 12 Adaptive comfort inside the building (a) and inside the courtyard (b) according to EN 15251

The courtyards, in a building that can be naturally ventilated through it, allow all this more easily. The contrasting of the above has been done by applying the adaptive comfort calculations of both the European and American standards to the interior temperatures of the Córdoba building studied as well as the monitored temperatures of its courtyard. The conclusion is clear: for the summer days studied, both inside the building and in the courtyard, the temperatures are for the majority of the time within the range of comfort considered by both regulations.
It is concluded that the courtyard is an ideal strategy in climates such as the Mediterranean for passive comfort. In this way, more energy-efficient designs are also achieved, as it allows users to dispense with mechanical air conditioning for the longest possible time, which saves significant amounts of energy. Finally, when it is necessary to use it, you can utilize the cooler air in the courtyard for the air conditioning which will still save energy thanks to the microclimate of the courtyard. Few strategies can be so complete..

8. Conclusions.

In light of the experimental and simulation results, it can be concluded that the design of courtyards in Mediterranean buildings has the following advantages:

- They allow the creation of outdoor spaces with microclimates that moderate the temperature in warm climates, whilst having a neutral effect in colder climates and winter conditions. These microclimates have traditionally been used to passively improve the performance of these buildings. However, it is also possible to use this technique in contemporary designs, introducing this cool air into the air conditioning system and improving the energy performance of the building. To evaluate this, a better quantitative knowledge of these phenomena is required.
- To improve the ventilation conditions avoiding overheating. The complex shapes and courtyards allow for smaller widths of interior spaces, with facades in different orientations, with different conditions of pressure of wind and temperature, which increases the opportunity for cross ventilation.
- Lastly, in Mediterranean climates, the architecture of more complex forms and courtyards usually provides a more satisfying human experience by maintaining contact with nature (Nicol et al., 2012). This improves adaptive thermal comfort and saves energy by keeping the air conditioning turned off for longer.

The development of precise energy tools for use during the early stages of the project is a priority for achieving energy efficiency. The present study highlights the fact that, as long as more sophisticated tools are not integrated into the design of the building, general recommendations of a reduced form factor, which generate more compact buildings are not valid in warm climates because of the complex interaction of form and climate. These excessively simplified recommendations can even be detrimental when attempting to achieve greater eco-efficiency in construction: they increase the risk of overheating (Sameni et al., 2015) and create a strong paradigm that makes it difficult to explore new innovative strategies based on more complex forms, as is the case of courtyards and their microclimatic conditions.

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