congresso da **reabilitação do património**

Aníbal Costa
Ana Velosa
Alice Tavares

universidade de aveiro
theoria poiesis praxis

congresso da **reabilitação do património**

Aníbal Costa
Ana Velosa
Alice Tavares

universidade de aveiro
theoria poiesis praxis

FICHA TÉCNICA

EDITORES
Aníbal Costa
Ana Velosa
Alice Tavares

PAGINAÇÃO E MONTAGEM
Briefing

CAPA
Ana Sofia Almeida (UA)

IMPRESSÃO
Tipografia A Lusitânia

TIRAGEM
200 exemplares

EDIÇÃO
1ª Edição - junho de 2017

ISBN
978-989-20-7623-2

DEPÓSITO LEGAL
428009/17

Universidade de Aveiro – Departamento de Engenharia Civil
Campus Universitário de Santiago | 3810-193 Aveiro

Estudo do desempenho térmico e avaliação das condições de conforto em edifícios antigos: casos de estudo do município de Ovar

Study of thermal performance and evaluation of comfort conditions in ancient buildings: case studies from the Portuguese municipality of Ovar

Jorge Fernandes[1], Alice Tavares[2], Ricardo Mateus[3], Helena Gervásio[4], Aníbal Costa[5]

[1]Centro de Território, Ambiente e Construção (C-TAC), Universidade do Minho. jepfernandes@me.com
[2]RISCO, Departamento de Engenharia Civil, Universidade de Aveiro. tavares.c.alice@ua.pt
[3]Centro de Território, Ambiente e Construção (C-TAC), Universidade do Minho. ricardomateus@civil.uminho.pt
[4]Institute for Sustainability and Innovation in Structural Engineering (ISISE), Universidade de Coimbra. hger@dec.uc.pt
[5]RISCO, Departamento de Engenharia Civil, Universidade de Aveiro. agc@ua.pt

Resumo

A última transposição para a legislação portuguesa da diretiva europeia sobre o desempenho energético de edifícios (EPBD), aumentou consideravelmente os requisitos exigidos tanto a edifícios novos como a reabilitações. Nos edifícios antigos, as características arquitetónicas e dos materiais existentes condicionam as soluções disponíveis. A solução de reabilitação energética mais eficaz passa muitas vezes por identificar e combinar estratégias que conduzam à solução de custo-ótimo. Para identificar as melhores opções dentro das linhas de intervenção possíveis (à escala das envolventes; estratégias passivas; equipamentos; sistemas de energia renovável), por forma a otimizar a intervenção e a melhorar o desempenho térmico e as condições de conforto, é necessário perceber o real desempenho deste tipo de edifícios.

Neste âmbito, este artigo apresenta os resultados preliminares do estudo de desempenho térmico e de conforto de um conjunto de casos de estudo localizados em Ovar. As monitorizações incluíram a medição de parâmetros higrotérmicos e inquéritos sobre a sensação térmica dos ocupantes.

Palavras-chave

Desempenho térmico; avaliação de conforto; monitorização; edifícios antigos

Abstract

The latest transposition into Portuguese legislation of the European Directive on the energy performance of buildings (EPBD) has considerably increased the requirements for both new buildings and rehabilitation. In old buildings, architectural and existing materials features condition the available solutions. The most effective energetic refurbishment solution often involves identifying and combining strategies that lead to a cost-optimal solution. To identify the best options within the possible lines of action (at the scale of the envelope, passive strategies, equipment, renewable energy systems), in order to optimize the intervention and improve thermal performance and comfort conditions, it is necessary to perceive the real performance of this type of buildings. Therefore, this paper presents the preliminary results of the study on thermal performance and comfort of a set of case studies located in Ovar. Monitoring included the measurement of hygrothermal parameters and surveys on occupants' thermal sensation.

Keywords

Thermal performance; Comfort assessment; monitoring; old buildings.

1. Introduction

The building sector is changing to a paradigm of energy-efficiency and environmental awareness. In fact, buildings are a key sector to implement energy and environmental measures, since it is one of the largest energy and natural resources consuming sectors [1], responsible for a third of global total CO2 emissions [2]. In the European Union (EU), for example, this change of paradigm is driven by the goals set in EU Directives. The directives on the Energy Performance of Buildings (EPBD) [3] and Energy Efficiency [4] have set the EU targets of saving 20% of primary energy consumption by 2020 and reducing greenhouse gas emissions by 80-95% by 2050 compared to 1990. Therefore, to accomplish the targets, new high-performance building concepts have been defined, as the "nearly zero-energy buildings" (nZEB), where energy demand must be offset by renewable energy sources [3]. The first steps to achieving a high-performance building are a reduction in energy demand for HVAC, by optimizing solar orientation and built form and by increasing envelope's insulation levels. Nevertheless, these actions are not always simple to implement in the existing building stock. Thus, in existing buildings, the most cost-effective renovation solutions are frequently a combination of energy-efficiency, energy conservation, and carbon emissions reduction measures. In the case of Portugal, according to Ferreira *et al.* [5], the housing stock built in the 1990s can move to a nearly zero-energy building scenario without major difficulties, considering the introduction of renewables on buildings that meet the cost-optimal levels. However, in the case of old buildings, traditional building materials and architectural features limit the range of available solutions. The most effective energy-renovation solution is frequently a combination of the best strategies that lead to a cost-optimal solution. Therefore, for each building, there is the need to identify the best solutions within the possible actions (envelope; passive strategies; equipment, renewable energy systems). The diversity of traditional construction systems found in Portuguese architecture makes necessary to understand the real performance of this type of buildings. With this information is possible to perceive how they can be improved to meet the new requirements of energy and thermal performances, and optimize the renovation operation.

In this sense, this paper aims at contributing to the research field by presenting the preliminary results of the study of thermal performance and comfort priorities in a set of building case studies located in the Ovar municipality. The study included in-situ measurements of hygrothermal parameters and surveys on occupant thermal sensation.

2. Geography, climate, and architecture in Ovar

Ovar is a small town located in the district of Aveiro, in the centre region of Portugal. Once a fishing and salt port [6], [7], the town lost this function due to the progressive retreat of the sea line during centuries and is now at approximately 4,5 km far from the coastline. The town is implanted in a flat area with a valley and is divided by a small river, formed by the confluence of two brooks that flow into the Aveiro Estuary. Ovar has a sprawled urban mesh characterised by buildings mainly with 1 or 2 floors. Presently, there are several buildings from the 19th and beginning of the 20th centuries, as the case studies presented in this paper. This bourgeoisie architecture has normally symmetrical facades design with a high front door in the center. The period of construction reflects the preferences at the time, in a moment of return of Portuguese entrepreneur from Brazil (as the case of Costa's house with a characteristic platband), but also a crescent capacity of builders through the implementation of railway which brought the opportunity of more accessible construction materials, as the granite applied on the facades.

The town is implanted on sandy soil. However, the soils from nearby areas at East are not only very fertile but characterized by the presence of gravel, phyllite, and schists associated to luvisols (i.e. soils that are rich in clay) [8]. In the absence of proper stone for building conventional masonry [6], local population had to use the locally-available resources as building materials. Soil's features determined the materials and the building's systems used. Thus, the most widespread materials/building systems in Ovar's architecture are walls built with adobe or with a mix of small stones (or gravel) with clay (Fig. 1).

The climate of Ovar is influenced by the proximity to the Atlantic Ocean. The region has a temperate climate, sub-type Csb according to Köppen climate classification, characterised by rainy winters and dry or temperate summers [9]. The annual average mean air temperature is of 15ºC, being of 12,5ºC in Winter and of 20ºC in Summer [9]. Regarding precipitation, the annual average number of days with precipitation ≥ 1 mm is of 125, while the annual average total rainfall is of 1000 mm, being December the month with the highest values and July the driest month [9].

Figure 1. Materials used in Ovar's constructions. (left) mix of stone gravel and clay wall; (right) adobe wall.

3. Methodology

The methodology adopted in this study aims to understand the thermal performance and comfort of dwellings with the same typology, built with the same building materials and in the same climatic zone, and establish a relation between occupant's perception and expectation regarding their comfort. To assess indoor thermal performance and comfort conditions of the case studies, in-situ assessments were divided into short and long-term monitoring. The short--term monitoring was carried out at least one time per season of the year and consisted of objective and subjective measurements. The objective measurements were performed with the purpose of quantitatively assess the thermal conditions within a specific room using a thermal microclimate instrument (model Delta OHM 32.1), in compliance with standards ISO 7726 [10] and ISO 7730 [11]. The location of the equipment is chosen according to occupants' distribution in the room. This data is used in the analysis of the thermal comfort conditions to determine the operative temperature, namely in the adaptive model of thermal comfort, as explained below. Simultaneously, were carried the subjective measurements, i.e., evaluate environment conditions by surveying the occupants. The survey allows to assess occupants' satisfaction according to ASHRAE thermal sensation scale and was based on the "Thermal Environment Survey" from ASHRAE standard 55 [12]. The surveys were carried for the rooms that occupants considered more comfortable and/or where they spend more time. The long-term monitoring was aimed at understanding the fluctuations of air temperature and relative humidity profiles, indoors and outdoors, throughout the various seasons in compliance with specified procedures and standards [10]–[12]. For this purpose, thermo-hygrometer sensors were installed outdoors and indoors, set to record data at 30 min intervals. During these measurements, occupants fulfilled an occupancy table where they recorded how they had used the building, i.e., if they used heating or cooling systems, promoted ventilation, etc.

Thermal comfort conditions were evaluated considering an adaptive model of thermal comfort, the most adequate for naturally conditioned areas. In order to be more representative of the Portuguese reality, the chosen model was the one developed in the National Laboratory of Civil Engineering (LNEC) by Matias [13]. In this model, thermal comfort is only verified when a person feels neutral and simultaneously shows preference to keep that neutrality. The thermal environment condition point is determined using a chart that correlates Operative temperature (Θo) with Outdoor running mean temperature (Θrm).

4. Thermal performance study and comfort conditions assessment

4.1 Description of the case studies

4.1.1 Case study 1 – Costa's house

Case study 1 is on the East side of the town. The building is integrated into the urban mesh, in a group of buildings forming a small public square. Its facades are facing north, west (street) and east (courtyard). The gross floor area is approximately 250 square meters divided into two storeys. In the ground floor, there are the living room, the garage and storage rooms. In the first floor, at West are the bedrooms and at East the dining room and the kitchen (Fig. 2). It was not possible to determine exactly the date of construction but, according to the owners, it is probably from the 19th century. Regarding the building systems, it was not possible to determine the materials used in the building. Nevertheless, it is highly probable that the materials used are the most common in this type of buildings in Ovar, as above mentioned. Thus, the building envelope consists of walls built with a mix of small stones and clay (average thickness of 60cm), with a pitched roof, wooden doors and wooden framed single glazed windows in the main façade and aluminium framed double glazed windows in the rear facade. Indoors, the partitions walls are in *tabique* – a wooden framed structure where the spaces between studs are fulfilled with small stones, bricks or clay.

Figure 2. (left) External view; (right) Floor plans showing the position of measuring instruments (1—living room; 2—bedroom; 3—dining room; 4—kitchen).

4.1.2 Case study 2 – Begasse's house

Case study 2 is on the West side of the town. The building is a detached house and its facades are facing north (courtyard), south (street), west and east. The gross floor area is approximately 230 square meters divided into two storeys. On the ground floor are the living room, technical room and the storage room. On the first floor, at south are the main bedrooms and at north the kitchen (Fig. 3). It was not possible to determine the date of construction but, according to the owners, it is probably from the 20th century. The building envelope consists of walls built with a mix of small stones and clay (average thickness of 65cm), with a pitched roof, wooden doors and wooden framed single glazed windows. Indoors, the partitions walls are in *tabique*.

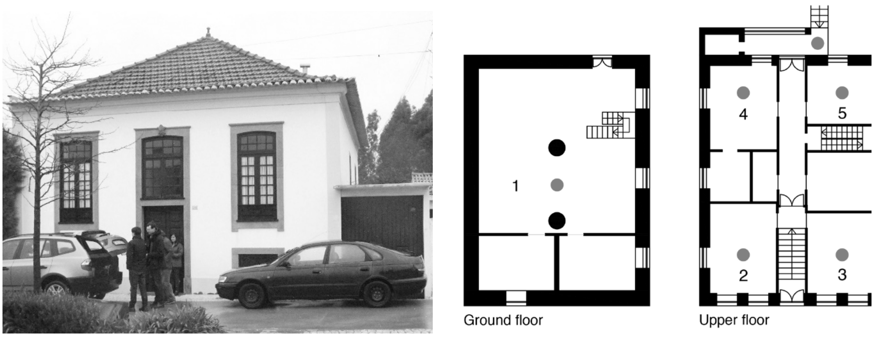

Figure 3. (left) External view; (right) Floor plans showing the position of measuring instruments (1—living room; 2—bedroom 2; 3—bedroom1; 4—kitchen; 5—bedroom3).

4.2 Hygrothermal monitoring and comfort assessment

The thermal performance monitoring was carried out for all seasons of the year. However, in this paper, only the results obtained for the two most demanding seasons in what thermal comfort is concerned, i.e., winter and summer, are addressed and discussed. The summer monitoring was conducted over the period from 21st June to 19th September 2016 and the winter monitoring over the period from 21st December to 3rd February 2017.

4.2.1 Summer monitoring

From the analysis of the results, it is possible to verify that during summer, outdoor mean air temperature was of about 21°C. The maximum air temperature was around 25°C in most of the days, surpassing 30ºC in some days. Minimum air temperature during the monitoring period was of about 14ºC. Outdoor mean relative humidity was around 70% while maximum and minimum values were around 90 and 30%, respectively.

In case study 1, indoor rooms showed a stable air temperature profile (Fig. 4). During all the monitoring period, the mean air temperature in indoor rooms was around 22-24°C. In the bedroom, the maximum air temperature was higher than in other rooms, probably due to solar exposure of the main facade (west) and also by the higher heat transfer coefficient of the single-glazed windows. In opposition, the living room had a maximum air temperature between 3-5ºC lower than the other monitored rooms (Fig. 4). The high thermal inertia of walls and floor and the fact that it has less glazed area, is probably the reason for the milder temperature profile when compared with the remaining upper floor rooms. In case study 2, indoor monitoring results show that all the inhabited rooms have a stable temperature profile, with mean values around 22-23ºC (Fig. 4), and maximum and minimum temperatures within thermal comfort range values most of the time. The living room had the most stable profile with higher minimum temperature (20.4ºC) and lower maximum temperature (25ºC). Its position on the ground floor, partially buried, and the high mass walls allow stabilizing the temperature. In both cases studies, beyond the thermal inertia, all the indoor rooms are naturally ventilated during the morning, what contributes for removing heat loads and cool the house.

Regarding the relative humidity (Fig. 5), for both case studies, the indoor mean values recorded are high and between 60-70% for all rooms, above of what it is recommended (between 40-60% [14]). The profiles are stable with slight daily variations in some rooms, probably due to the opening of windows and doors for ventilation. During the days with lower outdoor relative humidity, indoor values were higher. This is certainly due to the hygroscopic inertia of the walls, made of earthen materials.

The assessment of the summer season comfort conditions was done in case study 1 for the kitchen/dining room and in case study 2 for the living room (Fig. 6). In both cases, from the analysis of the charts, it was found that the rooms had a comfortable thermal environment, within the comfort range but close to the lower limit. In the subjective assessment carried out, two occupants showed to be "neutral" (comfortable) and one as "slightly cool" in the thermal sensation scale, confirming the objective measurements. Although the results from the short--term measurements represent one day, the conditions of thermal comfort can be extrapolated to almost all days, since there is a strong relation of dependency between the air temperature and the operative temperature [13].

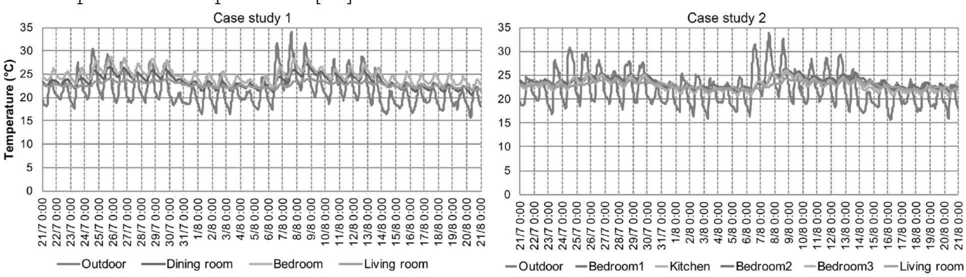

Figure 4. Indoor and outdoor air temperature profiles during summer season. (left) Case Study 1; (right) Case Study 2

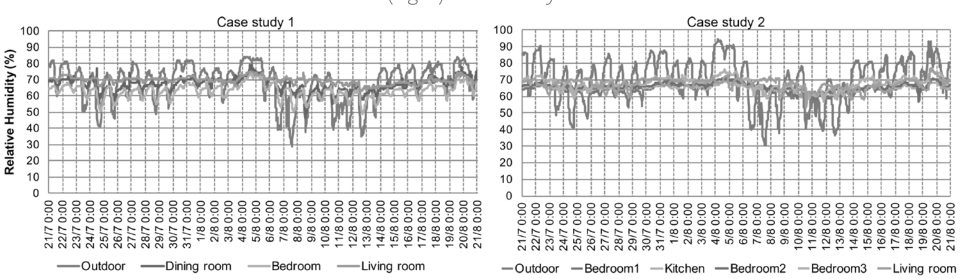

Figure 5. Indoor and outdoor relative humidity profiles during summer season. (left) Case Study 1; (right) Case Study 2

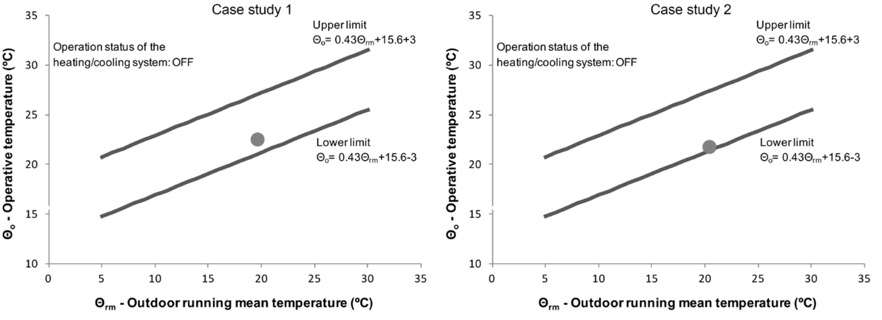

Figure 6. Adaptive comfort chart for summer monitoring without heating/cooling systems. (left) Case study 1 – Thermal comfort temperature (operative temperature) in the dining room/kitchen; (right) Case study 2 – Thermal comfort temperature (operative temperature) in the living room.

4.2.2 Winter monitoring

During the monitoring, outdoor mean air temperature was of about 9°C. The maximum air temperature was around 17°C but in most of the days was around 12-13ºC. The minimum air temperature during the monitoring period was of 0ºC. Outdoor mean relative humidity was around 85% while maximum and minimum values were around 100 and 47%, respectively.

In case study 1, indoor rooms showed air temperature profiles below 18ºC during the monitoring (Fig. 7), with mean values between 12-14ºC. Maximum air temperature in dining room/kitchen and bedroom was around 18-19ºC. The relative stability in these rooms was due to the thermal inertia but also to the use of portable electric heaters that were frequently switched on during the monitoring. In case study 2, the indoor temperature profiles (Fig. 7) show significant variations in regular periods of time. These variations and temperature peaks are due to the occupation profile, i.e, the house is permanently occupied mainly three days per week, and in those days temperature rises very rapidly when the central heating system is activated. When the heating system is turned off, air temperature decreases slowly through the following days until “stabilizes” around maximum outdoor temperature values, however, low. In this case, the use of the central heating system (boiler + radiators) allowed maintaining indoor temperature within comfort range values. However, in case study 1, is possible to see that the type of heating system used was not enough to ensure comfort conditions in most of the days. Considering the relative humidity, for both cases indoor spaces had relatively stable profiles with mean values between 60-70% (Fig. 8). In case study 2, when the heating system is activated, values decreased and stabilized between 40-60%, a boundary that is adequate for human health. In this case, the living room has the lower values, but this is due to the use of a dehumidifier device. Although the values recorded for both cases are high for a healthy indoor environment, are stable and considerably lower than those recorded outdoors. It is also possible to verify that the mean values between the two seasons are very similar. Climatic factors, namely the influence of the ocean, is a strong reason for frequent high relative humidity values.

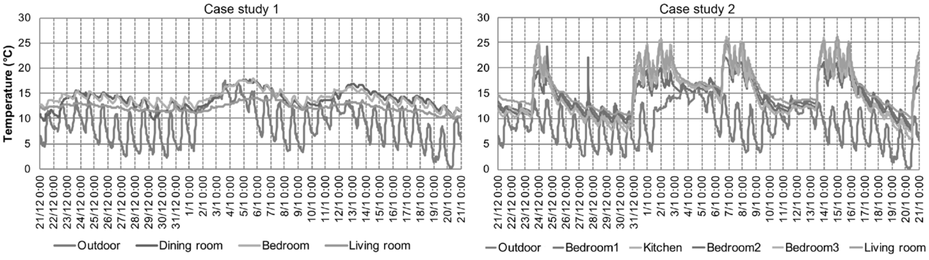

Figure 7. Indoor and outdoor air temperature profiles during winter season. (left) Case Study 1; (right) Case Study 2.

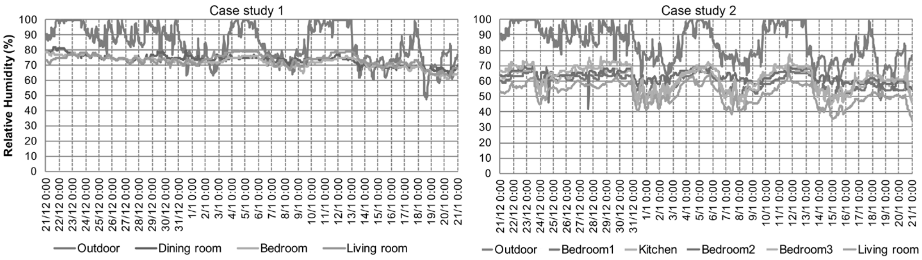

Figure 8. Indoor and outdoor relative humidity profiles during winter season. (left) Case Study 1; (right) Case Study 2.

The assessment of the winter season comfort conditions was done in case study 1 was done in case study 1 for the kitchen/dining room and in case study 2 for the living room (Fig. 9). In case study 1, the kitchen/dining room had a thermal environment in the lower limit of the comfort range, even with heating equipment turned on. In the subjective assessment, three occupants answered as being "neutral" (comfortable) and two as "slightly warm". Although the objective measurements show that room's environment is in the lower limit of the comfort range, two occupants answered as being "slightly warm", in the opposite limit. The explanation for this result is that these occupants were the ones closest to the electric heater. In case study 2, with the heating system activated, the living room had a good thermal environment (Fig. 9). In the subjective assessment, two occupants answered as being "slightly warm", one as being "hot" and one as being "slightly cool" in the thermal sensation scale. Although the objective measurements showed that the room had a good thermal environment, almost in the middle of the comfort range, none of the occupants answered as being comfortable. This result has several explanations. The first is the thermal resistance of clothes, the second is that one occupant was closest to the heat radiator and the other was the closest to the external wall, being the two influenced by the radiation effect, one receiving heat from the radiator and the other losing heat to the cool wall. The measurements in the two cases reflect the complexity of assessing thermal comfort and the importance of choosing an adequate point for performing the measurements, they also show the difference between occupants and the need to perform longer measurements in order to force occupants to adapt their clothes to the environment they are in.

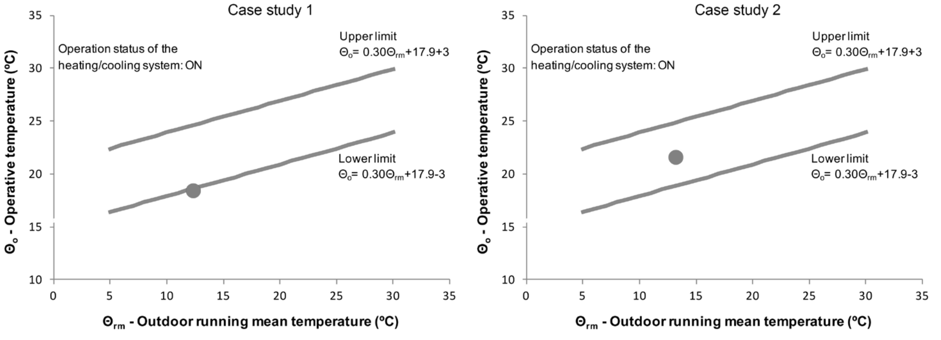

Figure 9. Adaptive comfort chart for winter monitoring with heating system. (left) Case study 1 – Thermal comfort temperature (operative temperature) in the dining room/kitchen; (right) Case study 2 – Thermal comfort temperature (operative temperature) in the living room.

5. Conclusions

The preliminary results of the thermal environment monitoring carried out in the two case studies, support that was possible to achieve indoor thermal comfort during cooling season by passive means alone. During winter, in both case studies, indoor thermal conditions were below the comfort range and the periods of thermal discomfort had to be overcome by using heating systems. It was observed that indoor temperature and relative humidity profiles were relatively stable in both seasons. The thermal and hygroscopic inertia of the envelope, mainly schist+clay and adobe walls with thickness between 0.50-0.65cm, has a positive influence in this behaviour. An example is case study 2, where after turning off the heating system, air temperature takes about a week to decrease to the previous levels. The surveys on occupants' thermal comfort corroborated the objective assessments, although with some discrepancies in winter assessment. It should be noted occupants' action in the regulation of their comfort conditions (e.g., promotion of morning ventilation during the summer period). Therefore, this is an on-going research work that intends to collect more detailed data of a set of 4 case studies, in order to understand their thermal performance and identify energy-efficiency renovation solutions that can improve comfort conditions.

Acknowledgments

The authors would like to acknowledge the support granted by the Portuguese Foundation for Science and Technology (FCT), in the scope of the Doctoral Program Eco-Construction and Rehabilitation (EcoCoRe), to the Ph.D. scholarship with the reference PD/BD/113641/2015 and to postdoctoral support with the reference SFRH/BPD/113053/2015, that were fundamental for the development of this study. The authors also wish to thank the owners of case study buildings, Mr. Costa and Mr Begasse, for helping and supporting this research work.

References

[1] B. Berge, The Ecology of Building Materials, 2nd ed., Oxford: Elsevier, 2009.

[2] D. Ürge-Vorsatz, L. D. Danny Harvey, S. Mirasgedis, and M. D. Levine, "Mitigating CO2 emissions from energy use in the world's buildings," Build. Res. Inf., vol. 35, no. 4, pp. 379–398, Aug. 2007.

[3] European Parliament and of the Council, "Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings," Strasbourg, 2010.

[4] European Parliament and of the Council, "Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC," Strasbourg, 2012.

[5] M. Ferreira, M. Almeida, A. Rodrigues, and S. M. Silva, "Comparing cost-optimal and net-zero energy targets in building retrofit," Build. Res. Inf., vol. 44, no. 2, pp. 188–201, Feb. 2016.

[6] A. Pinho Leal, Portugal antigo e moderno: diccionario geographico, estatistico, chorographico, heraldico, archeologico, historico, biographico e etymologico de todas as cidades, villas e freguezias de Portugal e de grande numero de aldeias. Vol. 6. Lisboa: Livraria Editora Mattos Moreira & companhia, 1873.

[7] M. Oliveira, Ovar na Idade Média. Ovar: Câmara Municipal de Ovar, 1967.

[8] APA, "Atlas Digital do Ambiente. SNIAmb - Sistema Nacional de Informação de Ambiente." [Online]. Available: http://sniamb.apambiente.pt/Home/Default.htm. [Accessed: 09-Mar-2017].

[9] AEMET and IM, Atlas Climático Ibérico: Temperatura do Ar e Precipitação (1971-2000)/Iberian Climate Atlas: Air Temperature and Precipitation (1971/2000). 2011.

[10] ISO7726, "Ergonomics of the thermal environment e instruments for measuring physical quantities," 2002.

[11] ISO7730, "Ergonomics of the thermal environment: Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria," 2005.

[12] ASHRAE, "ANSI/ASHRAE Standard 55 – Thermal Environmental Conditions for Human Occupancy," Atlanta, 2010.

[13] L. Matias, TPI65 - Desenvolvimento de um modelo adaptativo para definição das condições de conforto térmico em Portugal. Lisboa: Laboratório Nacional de Engenharia Civil/National Laboratory of Civil Engineering, 2010.

[14] T. Morton, Earth masonry – design and construction guidelines. Berkshire: HIS BRE Press, 2008.

Estudo do desempenho térmico e avaliação das condições de conforto em edifícios antigos: casos de estudo do município de Ovar

Study of thermal performance and evaluation of comfort conditions in ancient buildings: case studies from the Portuguese municipality of Ovar

Jorge Fernandes
Centro de Território, Ambiente e Construção (C-TAC), Universidade do Minho.
jepfernandes@me.com

Alice Tavares
RISCO, Departamento de Engenharia Civil, Universidade de Aveiro.
tavares.c.alice@ua.pt

Ricardo Mateus
Centro de Território, Ambiente e Construção (C-TAC), Universidade do Minho.
ricardomateus@civil.uminho.pt

Helena Gervásio
Institute for Sustainability and Innovation in Structural Engineering (ISISE), Universidade de Coimbra. hger@dec.uc.pt

Aníbal Costa
RISCO, Departamento de Engenharia Civil, Universidade de Aveiro. agc@ua.pt

Resumo

A última transposição para a legislação portuguesa da diretiva europeia sobre o desempenho energético de edifícios (EPBD), aumentou consideravelmente os requisitos exigidos tanto a edifícios novos como a reabilitações. Nos edifícios antigos, as características arquitetónicas e dos materiais existentes condicionam as soluções disponíveis. A solução de reabilitação energética mais eficaz passa muitas vezes por identificar e combinar estratégias que conduzam à solução de custo-ótimo. Para identificar as melhores opções dentro das linhas de intervenção possíveis (à escala das envolventes; estratégias passivas; equipamentos; sistemas de energia renovável), por forma a otimizar a intervenção e a melhorar o desempenho térmico e as condições de conforto, é necessário perceber o real desempenho deste tipo de edifícios.
Neste âmbito, este artigo apresenta os resultados preliminares do estudo de desempenho térmico e de conforto de um conjunto de casos de estudo localizados em Ovar. As monitorizações incluíram a medição de parâmetros higrotérmicos e inquéritos sobre a sensação térmica dos ocupantes.

Palavras-chave

Desempenho térmico; avaliação de conforto; monitorização; edifícios antigos.

Abstract

The latest transposition into Portuguese legislation of the European Directive on the energy performance of buildings (EPBD) has considerably increased the requirements for both new buildings and rehabilitation. In old buildings, architectural and existing materials features condition the available solutions. The most effective energetic refurbishment solution often involves identifying and combining strategies that lead to a cost-optimal solution. To identify the best options within the possible lines of action (at the scale of the envelope, passive strategies, equipment, renewable energy systems), in order to optimize the intervention and improve thermal performance and comfort conditions, it is necessary to perceive the real performance of this type of buildings.

Therefore, this paper presents the preliminary results of the study on thermal performance and comfort of a set of case studies located in Ovar. Monitoring included the measurement of hygrothermal parameters and surveys on occupants' thermal sensation.

Keywords

Thermal performance; Comfort assessment; monitoring; old buildings.

1. Introduction

The building sector is changing to a paradigm of energy-efficiency and environmental awareness. In fact, buildings are a key sector to implement energy and environmental measures, since it is one of the largest energy and natural resources consuming sectors [1], responsible for a third of global total CO_2 emissions [2]. In the European Union (EU), for example, this change of paradigm is driven by the goals set in EU Directives. The directives on the Energy Performance of Buildings (EPBD) [3] and Energy Efficiency [4] have set the EU targets of saving 20% of primary energy consumption by 2020 and reducing greenhouse gas emissions by 80-95% by 2050 compared to 1990. Therefore, to accomplish the targets, new high-performance building concepts have been defined, as the "nearly zero-energy buildings" (nZEB), where energy demand must be offset by renewable energy sources [3]. The first steps to achieving a high-performance building are a reduction in energy demand for HVAC, by optimizing solar orientation and built form and by increasing envelope's insulation levels. Nevertheless, these actions are not always simple to implement in the existing building stock. Thus, in existing buildings, the most cost-effective renovation solutions are frequently a combination of energy-efficiency, energy conservation, and carbon emissions reduction measures. In the case of Portugal, according to Ferreira *et al.* [5], the housing stock built in the 1990s can move to a nearly zero-energy building scenario without major difficulties, considering the introduction of renewables on buildings that meet the cost-optimal levels. However, in the case of old buildings, traditional building materials and architectural features limit the range of available solutions. The most effective energy-renovation solution is frequently a combination of the best strategies that lead to a cost-optimal solution. Therefore, for each building, there is the need to identify the best solutions within the possible actions (envelope; passive strategies; equipment, renewable energy systems). The diversity of traditional construction systems found in Portuguese architecture makes necessary to understand the real performance of this type of buildings. With this information is

possible to perceive how they can be improved to meet the new requirements of energy and thermal performances, and optimize the renovation operation.
In this sense, this paper aims at contributing to the research field by presenting the preliminary results of the study of thermal performance and comfort priorities in a set of building case studies located in the Ovar municipality. The study included in-situ measurements of hygrothermal parameters and surveys on occupant thermal sensation.

2. Geography, climate, and architecture in Ovar

Ovar is a small town located in the district of Aveiro, in the centre region of Portugal. Once a fishing and salt port [6], [7], the town lost this function due to the progressive retreat of the sea line during centuries and is now at approximately 4,5 km far from the coastline. The town is implanted in a flat area with a valley and is divided by a small river, formed by the confluence of two brooks that flow into the Aveiro Estuary.
Ovar has a sprawled urban mesh characterised by buildings mainly with 1 or 2 floors. Presently, there are several buildings from the 19th and beginning of the 20th centuries, as the case studies presented in this paper. This bourgeoisie architecture has normally symmetrical facades design with a high front door in the center. The period of construction reflects the preferences at the time, in a moment of return of Portuguese entrepreneur from Brazil (as the case of Costa's house with a characteristic platband), but also a crescent capacity of builders through the implementation of railway which brought the opportunity of more accessible construction materials, as the granite applied on the facades.
The town is implanted on sandy soil. However, the soils from nearby areas at East are not only very fertile but characterized by the presence of gravel, phyllite, and schists associated to luvisols (i.e. soils that are rich in clay) [8]. In the absence of proper stone for building conventional masonry [6], local population had to use the locally-available resources as building materials. Soil's features determined the materials and the building's systems used. Thus, the most widespread materials/building systems in Ovar's architecture are walls built with adobe or with a mix of small stones (or gravel) with clay (Fig. 1).
The climate of Ovar is influenced by the proximity to the Atlantic Ocean. The region has a temperate climate, sub-type Csb according to Köppen climate classification, characterised by rainy winters and dry or temperate summers [9]. The annual average mean air temperature is of 15ºC, being of 12,5ºC in Winter and of 20ºC in Summer [9]. Regarding precipitation, the annual average number of days with precipitation ≥ 1 mm is of 125, while the annual average total rainfall is of 1000 mm, being December the month with the highest values and July the driest month [9].

Figure 1. Materials used in Ovar's constructions. (left) mix of stone gravel and clay wall; (right) adobe wall.

3. Methodology

The methodology adopted in this study aims to understand the thermal performance and comfort of dwellings with the same typology, built with the same building materials and in the same climatic zone, and establish a relation between occupant's perception and expectation regarding their comfort. To assess indoor thermal performance and comfort conditions of the case studies, in-situ assessments were divided into short and long-term monitoring. The short-term monitoring was carried out at least one time per season of the year and consisted of objective and subjective measurements. The objective measurements were performed with the purpose of quantitatively assess the thermal conditions within a specific room using a thermal microclimate instrument (model Delta OHM 32.1), in compliance with standards ISO 7726 [10] and ISO 7730 [11]. The location of the equipment is chosen according to occupants' distribution in the room. This data is used in the analysis of the thermal comfort conditions to determine the operative temperature, namely in the adaptive model of thermal comfort, as explained below. Simultaneously, were carried the subjective measurements, i.e., evaluate environment conditions by surveying the occupants. The survey allows to assess occupants' satisfaction according to ASHRAE thermal sensation scale and was based on the "Thermal Environment Survey" from ASHRAE standard 55 [12]. The surveys were carried for the rooms that occupants considered more comfortable and/or where they spend more time. The long-term monitoring was aimed at understanding the fluctuations of air temperature and relative humidity profiles, indoors and outdoors, throughout the various seasons in compliance with specified procedures and standards [10]–[12]. For this purpose, thermo-hygrometer sensors were installed outdoors and indoors, set to record data at 30 min intervals. During these measurements, occupants fulfilled an occupancy table where they recorded how they had used the building, i.e., if they used heating or cooling systems, promoted ventilation, etc.
Thermal comfort conditions were evaluated considering an adaptive model of thermal comfort, the most adequate for naturally conditioned areas. In order to be more representative of the Portuguese reality, the chosen model was the one developed in the National Laboratory of Civil Engineering (LNEC) by Matias [13]. In this model, thermal comfort is only verified when a person feels neutral and simultaneously shows preference to keep that neutrality. The thermal environment condition point is determined using a chart that correlates Operative temperature (Θo) with Outdoor running mean temperature (Θrm).

4. Thermal performance study and comfort conditions assessment

4.1 Description of the case studies

4.1.1 Case study 1 – Costa's house

Case study 1 is on the East side of the town. The building is integrated into the urban mesh, in a group of buildings forming a small public square. Its facades are facing north, west (street) and east (courtyard). The gross floor area is approximately 250 square meters divided into two storeys. In the ground floor, there are the living room, the garage and storage rooms. In the first floor, at West are the bedrooms and at East the dining room and the kitchen (Fig. 2). It was not possible to determine exactly the date of construction but, according to the owners, it is probably from the 19th century. Regarding the building systems, it was not possible to determine the materials used in the building. Nevertheless, it is highly probable that the materials used are the most common in this type of buildings in Ovar, as above mentioned. Thus, the building envelope consists of walls built with a mix of small stones and clay (average thickness of 60cm), with a pitched roof, wooden doors and wooden framed single glazed windows in the main façade and aluminium framed double glazed windows in the rear facade. Indoors, the partitions walls are in *tabique* – a wooden framed structure where the spaces between studs are fulfilled with small stones, bricks or clay.

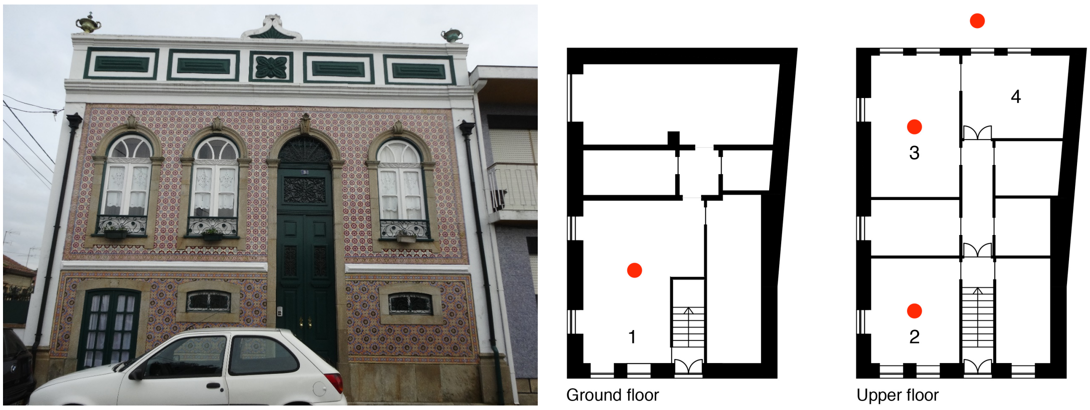

Figure 2. (left) External view; (right) Floor plans showing the position of measuring instruments (1—living room; 2—bedroom; 3—dining room; 4—kitchen).

4.1.2 Case study 2 – Begasse's house

Case study 2 is on the West side of the town. The building is a detached house and its facades are facing north (courtyard), south (street), west and east. The gross floor area is approximately 230 square meters divided into two storeys. On the ground floor are the living room, technical room and the storage room. On the first floor, at south are the main bedrooms and at north the kitchen (Fig. 3). It was not possible to determine the date of construction but, according to the owners, it is probably from the 20th century. The building envelope consists of walls built with a mix of small stones and clay (average thickness of 65cm), with a pitched roof, wooden doors and wooden framed single glazed windows. Indoors, the partitions walls are in *tabique*.

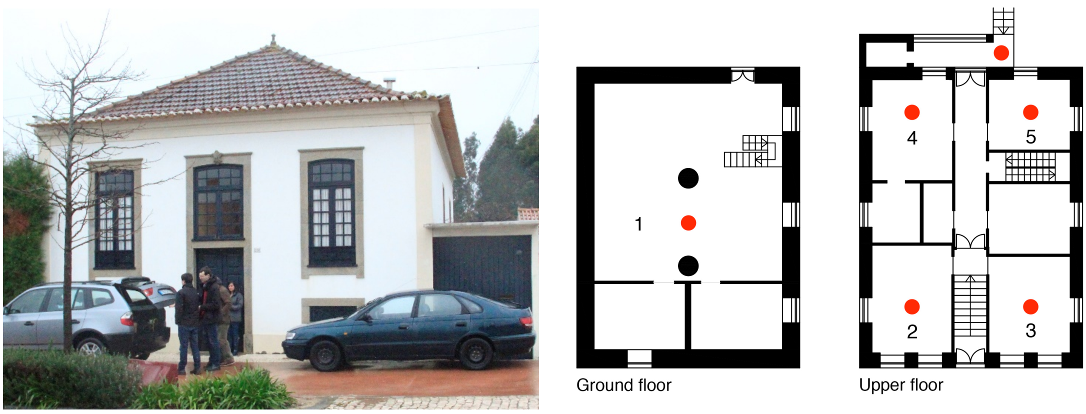

Figure 3. (left) External view; (right) Floor plans showing the position of measuring instruments (1—living room; 2—bedroom 2; 3—bedroom1; 4—kitchen; 5—bedroom3).

4.2 Hygrothermal monitoring and comfort assessment

The thermal performance monitoring was carried out for all seasons of the year. However, in this paper, only the results obtained for the two most demanding seasons in what thermal comfort is concerned, i.e., winter and summer, are addressed and discussed. The summer monitoring was conducted over the period from 21st June to 19th September 2016 and the winter monitoring over the period from 21st December to 3rd February 2017.

4.2.1 Summer monitoring

From the analysis of the results, it is possible to verify that during summer, outdoor mean air temperature was of about 21°C. The maximum air temperature was around 25°C in most of the days, surpassing 30ºC in some days. Minimum air temperature during the monitoring period was of about 14ºC. Outdoor mean relative humidity was around 70% while maximum and minimum values were around 90 and 30%, respectively.

In case study 1, indoor rooms showed a stable air temperature profile (Fig. 4). During all the monitoring period, the mean air temperature in indoor rooms was around 22-24°C. In the bedroom, the maximum air temperature was higher than in other rooms, probably due to solar exposure of the main facade (west) and also by the higher heat transfer coefficient of the single-glazed windows. In opposition, the living room had a maximum air temperature between 3-5ºC lower than the other monitored rooms (Fig. 4). The high thermal inertia of walls and floor and the fact that it has less glazed area, is probably the reason for the milder temperature profile when compared with the remaining upper floor rooms. In case study 2, indoor monitoring results show that all the inhabited rooms have a stable temperature profile, with mean values around 22-23ºC (Fig. 4), and maximum and minimum temperatures within thermal comfort range values most of the time. The living room had the most stable profile with higher minimum temperature (20.4ºC) and lower maximum temperature (25ºC). Its position on the ground floor, partially buried, and the high mass walls allow stabilizing the temperature. In both cases studies, beyond the thermal inertia, all the indoor rooms are naturally ventilated during the morning, what contributes for removing heat loads and cool the house.

Regarding the relative humidity (Fig. 5), for both case studies, the indoor mean values recorded are high and between 60-70% for all rooms, above of what it is recommended (between 40-60% [14]). The profiles are stable with slight daily variations in some rooms, probably due to the opening of windows and doors for ventilation. During the days with lower outdoor relative humidity, indoor values were higher. This is certainly due to the hygroscopic inertia of the walls, made of earthen materials.

The assessment of the summer season comfort conditions was done in case study 1 for the kitchen/dining room and in case study 2 for the living room (Fig. 6). In both cases, from the analysis of the charts, it was found that the rooms had a comfortable thermal environment, within the comfort range but close to the lower limit. In the subjective assessment carried out, two occupants showed to be “neutral” (comfortable) and one as “slightly cool” in the thermal sensation scale, confirming the objective measurements. Although the results from the short-term measurements represent one day, the conditions of thermal comfort can be extrapolated to almost all days, since there is a strong relation of dependency between the air temperature and the operative temperature [13].

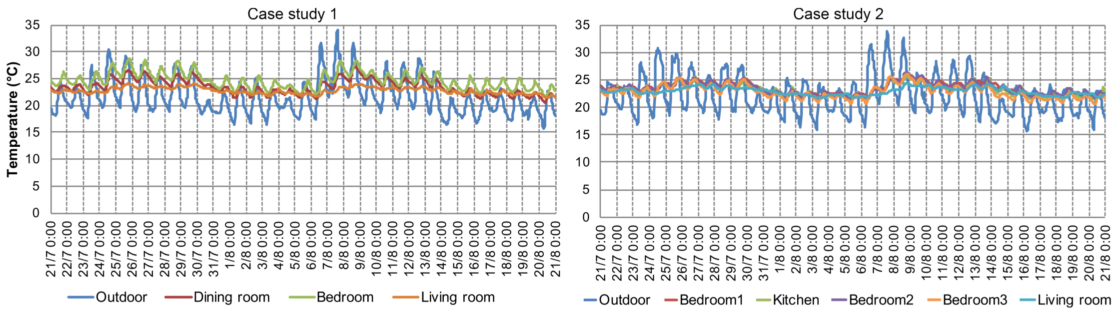

Figure 4. Indoor and outdoor air temperature profiles during summer season. (left) Case Study 1; (right) Case Study 2.

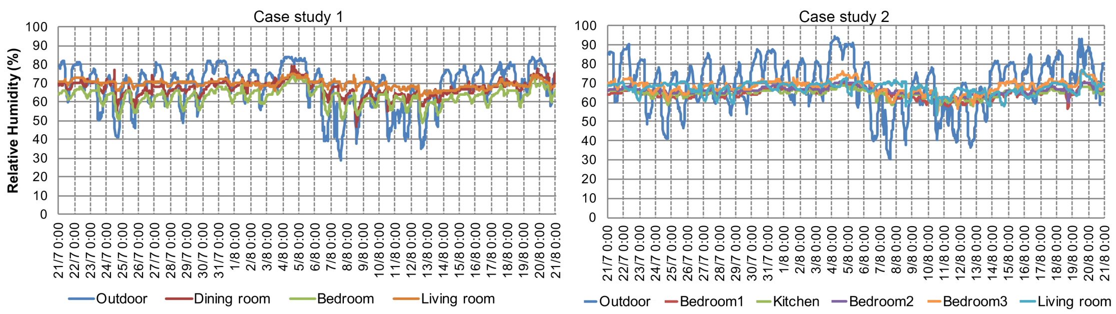

Figure 5. Indoor and outdoor relative humidity profiles during summer season. (left) Case Study 1; (right) Case Study 2.

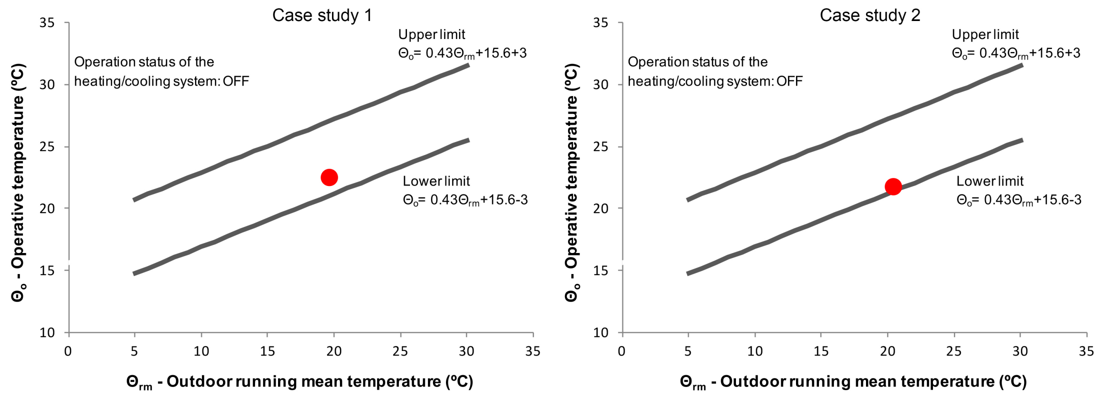

Figure 6. Adaptive comfort chart for summer monitoring without heating/cooling systems. (left) Case study 1 – Thermal comfort temperature (operative temperature) in the dining room/kitchen; (right) Case study 2 – Thermal comfort temperature (operative temperature) in the living room.

4.2.2 Winter monitoring

During the monitoring, outdoor mean air temperature was of about 9°C. The maximum air temperature was around 17°C but in most of the days was around 12-13ºC. The minimum air temperature during the monitoring period was of 0ºC. Outdoor mean relative humidity was around 85% while maximum and minimum values were around 100 and 47%, respectively.

In case study 1, indoor rooms showed air temperature profiles below 18ºC during the monitoring (Fig. 7), with mean values between 12-14ºC. Maximum air temperature in dining room/kitchen and bedroom was around 18-19ºC. The relative stability in these rooms was due to the thermal inertia but also to the use of portable electric heaters that

were frequently switched on during the monitoring. In case study 2, the indoor temperature profiles (Fig. 7) show significant variations in regular periods of time. These variations and temperature peaks are due to the occupation profile, i.e, the house is permanently occupied mainly three days per week, and in those days temperature rises very rapidly when the central heating system is activated. When the heating system is turned off, air temperature decreases slowly through the following days until "stabilizes" around maximum outdoor temperature values, however, low. In this case, the use of the central heating system (boiler + radiators) allowed maintaining indoor temperature within comfort range values. However, in case study 1, is possible to see that the type of heating system used was not enough to ensure comfort conditions in most of the days.
Considering the relative humidity, for both cases indoor spaces had relatively stable profiles with mean values between 60-70% (Fig. 8). In case study 2, when the heating system is activated, values decreased and stabilized between 40-60%, a boundary that is adequate for human health. In this case, the living room has the lower values, but this is due to the use of a dehumidifier device. Although the values recorded for both cases are high for a healthy indoor environment, are stable and considerably lower than those recorded outdoors. It is also possible to verify that the mean values between the two seasons are very similar. Climatic factors, namely the influence of the ocean, is a strong reason for frequent high relative humidity values.

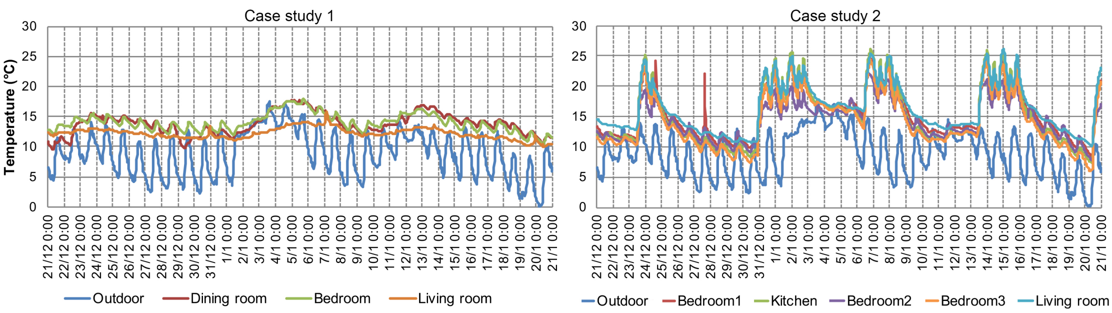

Figure 7. Indoor and outdoor air temperature profiles during winter season. (left) Case Study 1; (right) Case Study 2.

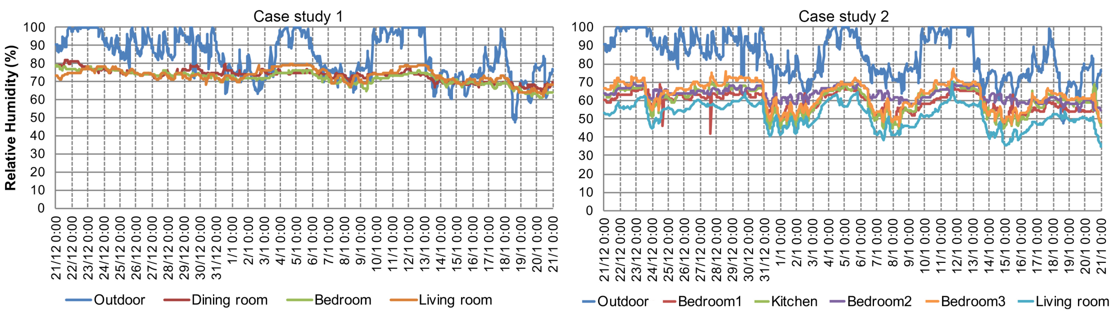

Figure 8. Indoor and outdoor relative humidity profiles during winter season. (left) Case Study 1; (right) Case Study 2.

The assessment of the winter season comfort conditions was done in case study 1 was done in case study 1 for the kitchen/dining room and in case study 2 for the living room (Fig. 9). In case study 1, the kitchen/dining room had a thermal environment in the lower limit of the comfort range, even with heating equipment turned on. In the subjective assessment, three occupants answered as being "neutral" (comfortable) and two as "slightly warm". Although the objective measurements show that room's environment is in the lower limit of the comfort range, two occupants answered as being "slightly warm", in the opposite limit. The explanation for this result is that these occupants were the ones closest to the electric heater. In case study 2, with the heating system activated, the living room had a good thermal environment (Fig. 9). In the subjective assessment, two occupants answered as being "slightly warm", one as being "hot" and one as being "slightly cool" in the thermal sensation scale. Although the objective measurements showed that the room had a good thermal environment, almost in the middle of the comfort range, none of the occupants answered as being comfortable. This result has several explanations. The first is the thermal resistance of clothes, the second is that one occupant was closest to the heat radiator and the other was the closest to the external wall, being the two influenced by the radiation effect, one receiving heat from the radiator and the other losing heat to the cool wall. The measurements in the two cases reflect the complexity of assessing thermal comfort and the importance of choosing an adequate point for performing the measurements, they also show the difference between occupants and the need to perform longer measurements in order to force occupants to adapt their clothes to the environment they are in.

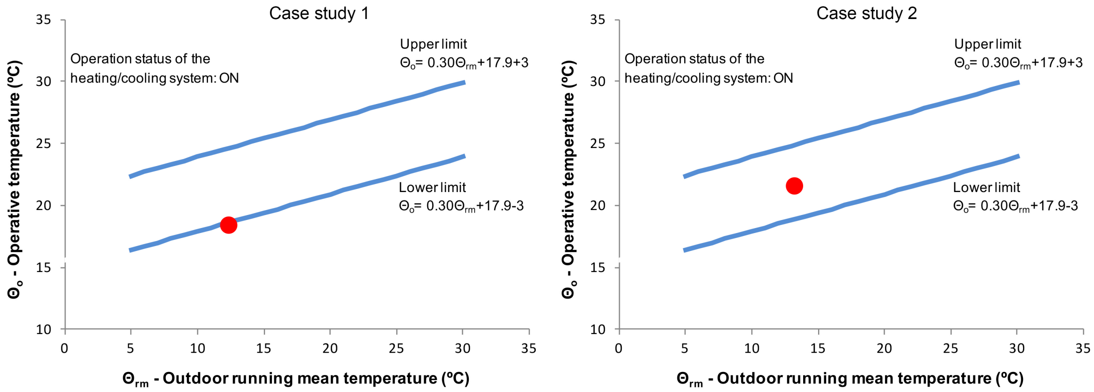

Figure 9. Adaptive comfort chart for winter monitoring with heating system. (left) Case study 1 – Thermal comfort temperature (operative temperature) in the dining room/kitchen; (right) Case study 2 – Thermal comfort temperature (operative temperature) in the living room.

5. Conclusions

The preliminary results of the thermal environment monitoring carried out in the two case studies, support that was possible to achieve indoor thermal comfort during cooling season by passive means alone. During winter, in both case studies, indoor thermal conditions were below the comfort range and the periods of thermal discomfort had to be overcome by using heating systems. It was observed that indoor temperature and relative humidity profiles were relatively stable in both seasons. The thermal and hygroscopic inertia of the envelope, mainly schist+clay and adobe walls with thickness between 0.50-0.65cm, has a positive influence in this behaviour. An example is case study 2, where after turning off the heating system, air temperature takes about a week to decrease to the previous levels. The surveys on occupants' thermal comfort corroborated the objective assessments, although with some discrepancies in winter assessment. It should be noted occupants' action in the regulation of their comfort conditions (e.g., promotion of morning ventilation during the summer period). Therefore, this is an on-going research work that intends to collect more detailed data of a set of 4 case studies, in order to understand their thermal performance and identify energy-efficiency renovation solutions that can improve comfort conditions.

Acknowledgments

The authors would like to acknowledge the support granted by the Portuguese Foundation for Science and Technology (FCT), in the scope of the Doctoral Program Eco-Construction and Rehabilitation (EcoCoRe), to the Ph.D. scholarship with the reference PD/BD/113641/2015 and to postdoctoral support with the reference SFRH/BPD/113053/2015, that were fundamental for the development of this study. The authors also wish to thank the owners of case study buildings, Mr. Costa and Mr Begasse, for helping and supporting this research work.

References

[1] B. Berge, *The Ecology of Building Materials*, 2nd ed., Oxford: Elsevier, 2009.

[2] D. Ürge-Vorsatz, L. D. Danny Harvey, S. Mirasgedis, and M. D. Levine, "Mitigating CO2 emissions from energy use in the world's buildings," *Build. Res. Inf.*, vol. 35, no. 4, pp. 379–398, Aug. 2007.

[3] European Parliament and of the Council, "Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings," Strasbourg, 2010.

[4] European Parliament and of the Council, "Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC," Strasbourg, 2012.

[5] M. Ferreira, M. Almeida, A. Rodrigues, and S. M. Silva, "Comparing cost-optimal and net-zero energy targets in building retrofit," *Build. Res. Inf.*, vol. 44, no. 2, pp. 188–201, Feb. 2016.

[6] A. Pinho Leal, *Portugal antigo e moderno: diccionario geographico, estatistico, chorographico, heraldico, archeologico, historico, biographico e etymologico de todas as cidades, villas e freguezias de Portugal e de grande numero de aldeias. Vol. 6*. Lisboa: Livraria Editora Mattos Moreira & companhia, 1873.

[7] M. Oliveira, *Ovar na Idade Média*. Ovar: Câmara Municipal de Ovar, 1967.

[8] APA, "Atlas Digital do Ambiente. SNIAmb - Sistema Nacional de Informação de Ambiente." [Online]. Available: http://sniamb.apambiente.pt/Home/Default.htm. [Accessed: 09-Mar-2017].

[9] AEMET and IM, *Atlas Climático Ibérico: Temperatura do Ar e Precipitação (1971-2000)/Iberian Climate Atlas: Air Temperature and Precipitation (1971/2000)*. 2011.

[10] ISO7726, "Ergonomics of the thermal environment e instruments for measuring physical quantities," 2002.

[11] ISO7730, "Ergonomics of the thermal environment: Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria," 2005.

[12] ASHRAE, "ANSI/ASHRAE Standard 55 – Thermal Environmental Conditions for Human Occupancy," Atlanta, 2010.

[13] L. Matias, *TPI65 - Desenvolvimento de um modelo adaptativo para definição das condições de conforto térmico em Portugal*. Lisboa: Laboratório Nacional de Engenharia Civil/National Laboratory of Civil Engineering, 2010.

[14] T. Morton, *Earth masonry – design and construction guidelines*. Berkshire: HIS BRE Press, 2008.