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447 - Thermal Performance of Residential Buildings in Lisbon with Large Glazing Areas

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Abstract

This work presents the results of an experimental study of residential buildings (multi-family apartments) with glazing areas greater than 75% of the total façade area, and for different solar exposures in Lisbon. These buildings were designed after the implementation of the first Portuguese Buildings Thermal Regulation and they are intrinsically related with the construction and architecture practiced in the last few years. The analysis includes the thermal behaviour of the apartments selected for the study during the summer (2007) and winter (2007-2008). During the monitoring process important data were obtained to assist in the understanding of the thermal performance of the observed units. The main thermal exchanges in a building generally take place through the transparent elements and these can be considered an element of great flexibility and adaptation to climatic variations. The mean of the interior temperature means in the different monitored compartments during the hot season was approximately 27ºC (some cases close to 29ºC), while in the cold season 21ºC (some cases close to 18ºC).

Keywords: Glazing areas, thermal behaviour, heating, cooling, thermal comfort

1. Introduction

The energetic optimization reveals how important is the building envelope, as the main element between the exterior and interior conditions. The conduction and convection transfers through glass present a similar behaviour of the opaque elements with the possibility of the air change control between the interior and exterior - opening or closing the windows. Meanwhile, radiation becomes the principal factor because its portion is transmitted directly through the glass to the interior.

The non-opaque envelope can be considered an element of great importance in the control of radiation, ventilation and natural illumination. A more dynamic element, easier to adapt and adjust to obtain the desired interior conditions, in other words, it presents a comparatively greater degree of adaptation control and flexibility to the climatic variations than the opaque envelope. In addition, glass and other transparent materials are essential elements for the successful application of the majority of the passive solar heating systems. The heat transfers occur differently depending on the types of materials and proportions being applied in a specific building (opaque and non-opaque envelope).

2. Study Framework

An increasing interest and application of the glass material in architecture and Portuguese construction can be observed through the buildings of the built where it is more used in the service buildings-Fig.1.

Fig. 1. Service Buildings (Lisbon).

It is a common sight in the service buildings (mainly office buildings) built in the last decades, the glass material as constituent part of the envelope and in considerable proportions. The residential buildings, usually present, lower glazing areas than the service buildings. Meanwhile, it is possible to note a growing increase in the glazing areas in the façades of the residential buildings built in the last decades (Fig. 2), and even, some of the residential buildings built in the last years have practically glassed façades similar to the service buildings, see Fig. 3.

Fig. 2. Evolution of residential buildings and glazing areas in the last decades (Valmor Awards).

Fig. 3. Residential buildings with glass façades (Lisbon, last years).

Large glazing areas in residential buildings are architectural solutions or options that allow a more homogeneous exterior aesthetic view, scenery contemplation, greater transparency and luminosity; while having a direct influence in the comfort of its occupants, and are determinant for the building thermal-energetic performance (large glazing areas in a residential unit increases the potential for heat gain or loss). The residential buildings highlighted in Fig. 3 were selected for this study. Some flats of these buildings were monitored through the summer (2007) and winter (2007-2008). In this way this work will show the main results and observations of the monitoring.

3. Description and Characterization of Buildings and Units Selected for the Study

3.1. Selected buildings for the study

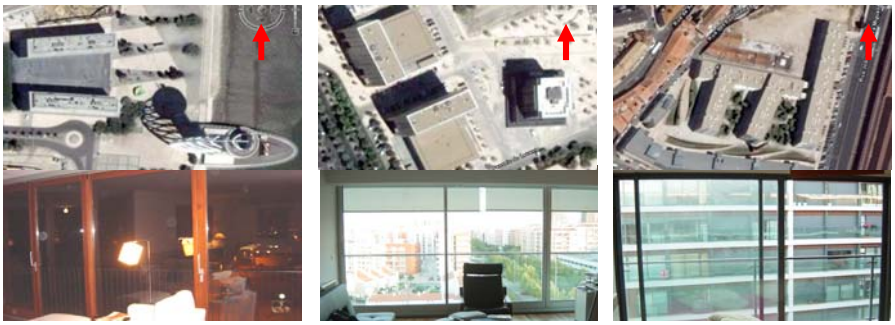

Fig. 4. Selected buildings for the study.

The residential buildings selected - Navitejo, Pertejo, Alcântara-Rio in Lisbon - were built after the implementation of the first Thermal Regulation, which impose minimum quality levels to the constructive solutions to be adopted in the opaque and non-opaque envelope (thermal insulation and double glasses introduction) to guarantee a better thermal and energetic performance of the buildings.

3.2. Features of buildings and flats selected to study

All the dwellings are located in the City of Lisbon in zones close to the Tejo River with scattered vegetation and with few obstructions (buildings or constructions). The set of monitored fractions was composed of 11 residences (located in the penthouse, intermediate and one with external floor), 21 compartments composed of living room and bedroom type environments.

The different solar exposures of the various adopted compartments represents the main orientations. These are 10 compartments with the main glassed façade practically to the south (South, SSE, and SSW), 4 to the west (WNW), 4 to the east (ENE) and 3 to the north (North and NNE). The majority of the environments selected present only one face in contact with the exterior (16 compartments) encompassing the principal solar dispositions.

	Facade(s) Exposed Orientation	Dwelling	Compartment	Location in Building	FF (Form Factor)	Glazing Facade(s) Orientation	Glazing Area/ Facade Area in Corresponding Exposition (%)	Total Glazing Area/ Floor Area (%)	Exterior Shading	Interior Shading	Cooling System (air conditioning)	Heating System
South	South +East	H1	living room	Intermediate	0.29	South, SSW, East	95% South, 40% East, 97% SSW	54%	horizontal shading (>)	screen	Yes	Yes
	SSE	H2	living room		0.16	SSE	83%	34%	horizontal shading + vertical awnings	-	No	
			bedroom		0.34		77%	69%		black out		
		H3	living room	Ext. Floor	0.49		83%	23%		-		
		H4	living room	Penthouse	0.48		80%	20%				
	SSE+WSW	H4	bedroom		0.81		91% SSE	49%		black out	No	
	SSW	H9	bedroom		0.54	SSW	81%	32%	horizontal shading (<) + blinds	-		
		H11	bedroom	Intermediate	0.15		81%	32%			No	
	SSW+WNW	H9	living room	Penthouse	0.59		40% SSW	16%			Yes	
		H11	living room	Intermediate	0.21			16%			No	No
West	WNW	H7	living room		0.16	WNW	81%	35%				
			bedroom		0.15		81%	32%				
		H8	living room	Penthouse	0.55		36%	15%				
			bedroom		0.54		81%	32%				
East	ENE	H5	living room	Intermediate	0.15	ENE	84%	34%	horizontal shading			Yes
			bedroom 1		0.20		90%	46%		black out		
			bedroom 2		0.34		77%	68%				
		H6	living room		0.10		82%	22%		-	Yes	
North	North/NNE	H1	bedroom		0.21	North	34% N	18%	horiz. Shad. (<<)	wood door	No	
		H10	living room		0.16	NNE	81%	33%	horizontal shading (<) + blinds	-		
	NNE+ESE	H10	bedroom		0.29	NNE	81% NNE	32%				

Navitejo Building Pertejo Building Alcântara-Rio Building

Fig. 5. Features of flats and compartments selected to study

The majority of the compartments (17) present glazing areas greater than 75% of the corresponding exposed face area (face in which the glass is inserted), in some cases this relation is close to 90%. In terms of floor area the compartment set presents glazing areas of between 15% and approximately 70%, in the majority of these relationships is of 25%-35%. The form factor (FF) varies in the selected sample between 0.1 and 0.5 (16 compartments).

All the fractions present transparent double glass with metal frames, only a fraction of Navitejo building had wood frame. In relation to the exterior shading systems the sample presents systems of the following types: horizontal shading (all buildings), blinds (Alcântara-Rio) and vertical awnings (Pertejo). The wall in contact with the exterior in the Navitejo and Pertejo Building fractions are composed of simple walls with exterior insulation. The thickness of the insulation of the exterior walls and roof are: 30mm in Navitejo, 40mm in Pertejo and 20mm-30mm in Alcântara-Rio.

4. Monitoring

A more detailed appreciation of the buildings were undertaken with the architecture projects (provided by the Studios and respective responsible architects), subsequently the monitoring was implemented during the months corresponding with the summer 2007 and the winter 2007-2008. Dwelling units of the same typology and similar layouts were selected (whenever possible) for the measurements in each of the adopted buildings. As mentioned in the previous section, it was possible to monitor similar apartments with different solar dispositions in different locations of the same building.

During the monitoring temperature and relative humidity sensors were installed (Mini data logger Testostor-175 provided for the study by INETI, normally in the living room and bedroom environments of the residential units selected. The monitoring took place in periods of approximately 15 days. The Data Loggers were positioned so that they would be as centralized as possible in relation to the respective environments being evaluated while not interfering with the resident's activities. The occupation and utilization pattern of each residential unit was also recorded during the measurements, this information was of relative importance for the interpretation and analysis of the recorded data.

The observations of the external conditions: temperature, relative humidity, wind velocity, wind direction and global horizontal radiation were obtained from the INETI Meteorological Station installed in the Solar XXI Building. In this way it became possible to assume the same external conditions for the all housing units with the data from the Meteorological Station INETI, and then obtaining a data and information set that made possible the observation and verification of the thermal performance and comfort levels in the various monitored fractions in summer and winter situations.

5. Analysis of Data Obtained During the Monitoring

5.1. Summer measurements

During most of the monitoring periods the exterior temperatures were below 20ºC, approximately 35%-45% of the time. The monitoring periods corresponding to measurements performed in housing units 8, 9 and 10 showed temperatures below 20ºC during 25% of the time, and the ones corresponding to 6 and 2 during a longer period of time (45%-50% of the time).

In the majority of the monitoring periods the exterior temperatures were between 20ºC and 25ºC (comfort) approximately 40% of the time; between 25ºC and 27ºC (near to comfort) approximately 9% of the time, and between 27ºC and 31ºC approximately 10% of the time. The periods corresponding to housing units 3, 8, 9 and 10 presented exterior temperatures between 27ºC and 31ºC during the longest periods of time (11% -16% of the time); and the ones corresponding to housing units 4 and 11 during the least time (3% - 6% of the time). Therefore, in a general way the exterior temperatures were below 25ºC during the different monitoring periods in close to 70%-85% of the time. Thus, the other temperatures, above 25ºC, are distributed in the remaining 15%-35%. For the Fig. 6 it is possible to conclude that none of the monitored compartments during the summer 2007 months showed temperatures below 20ºC.

The compartments that showed temperatures between 20ºC and 25ºC were mainly the ones with glazing areas oriented practically east, north and west (on average 6%-9% of the time). The compartment of dwelling 1, with glazing areas practically South+East, also showed temperatures between 20ºC and 25ºC in close to 13% of the time, while a compartment practically to the north in the same dwelling showed temperatures in these values approximately 41% of the time. Some compartments presented temperatures between 25ºC and 27ºC most of the time. These were those with glazing areas oriented practically to the north. Dwelling 10 presented temperatures within these values practically 85%-95% of the time.

Is noted that the housing units (7, 8, 9, 10 and 11) of the Building Alcântara-Rio, the only that have exterior shading systems of the blind type (beside a horizontal shading) most of the time showed temperatures between 25ºC-27ºC and 27ºC-29ºC, 92%-100% of the time. Being that the compartments with glazing areas to the: South presented temperatures between 27ºC-29ºC approximately 87% of the time; north showed temperatures 25ºC-27ºC approximately 90% of the time; west presented temperatures of 27ºC-29ºC approximately 35% of the time and temperatures of 25ºC-27ºC approximately 60% of the time.

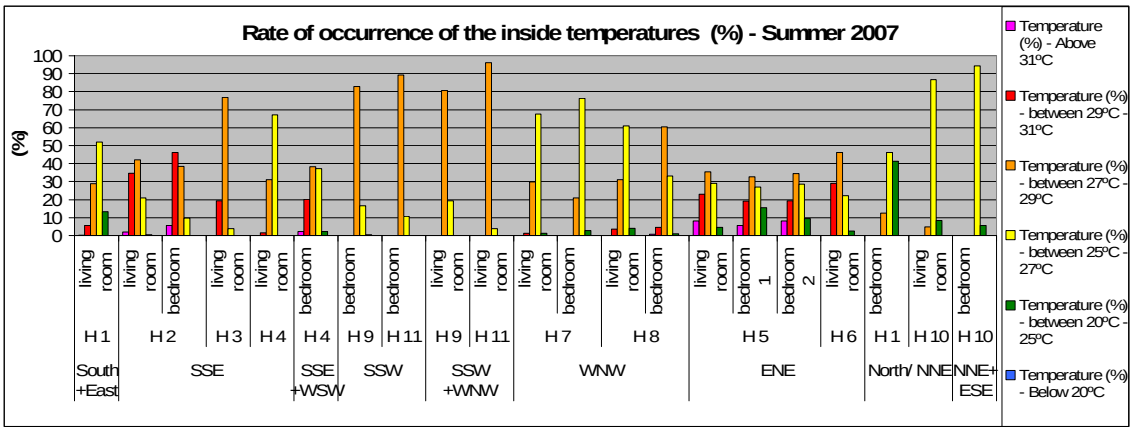

Fig. 6. Rate of occurrence of the inside temperatures for the different compartments - summer 2007.

The monitored housing units in buildings Pertejo (2, 3, 4, 5 and 6) and Navitejo (living room) without exterior shading presented temperatures practically distributed between 25ºC and ≥31ºC. The compartments with glazing areas practically east showed temperatures above 27ºC approximately 67% of the time. Housing units 2 and 3 presented temperatures above 27ºC in approximately 75%-95% of the time, with dwelling 2 presenting temperatures above 29ºC over 40% of the time. In Fig. 7 refers to the mean temperature values and it was concluded that:

Mean of the mean temperatures: were above 25ºC for all the monitored compartments with respective monitoring periods, being that for the majority of these it was approximately 27ºC. In some studied compartments with glazing areas practically to the south (South, SSE, SSW) the mean temperature was close to 28ºC. The studied compartments with glazing areas practically to the north (North, NNE) were the ones showing lower values of the mean temperature, close to 25,5 ºC.

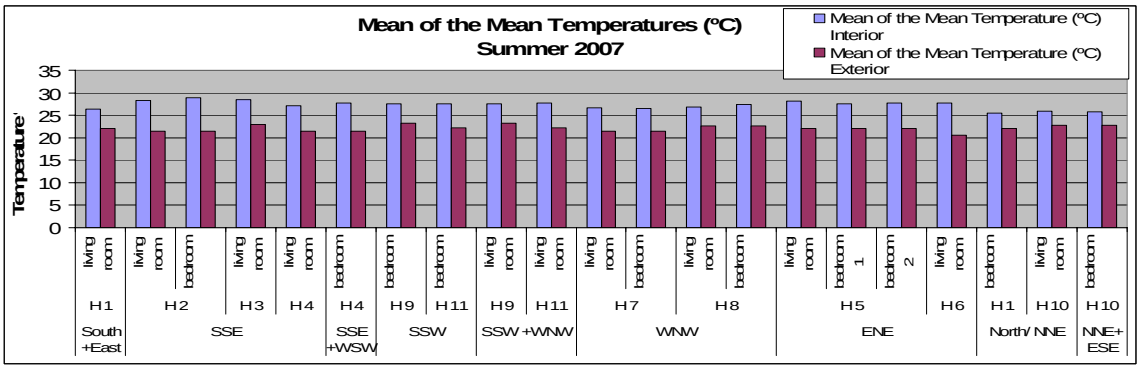

Fig. 7. Mean of the mean temperatures for the different compartments – summer 2007

Mean of the maximum temperatures: for the different compartments in the respective monitoring periods were close to 0,5ºC to 0,9ºC higher than the mean temperature. Therefore, for most of the monitored compartments the average of the maximums was approximately 28ºC.

Mean of the minimum temperatures: were close to or higher than 25ºC for all the housing units in the respective monitoring periods. The average of the minimum temperatures was close to 27ºC for the compartments with glazing areas practically to the south, while for the compartments with glazing areas practically east and west was approximately 26ºC and for those with glazing areas practically to the north was approximately 25ºC.

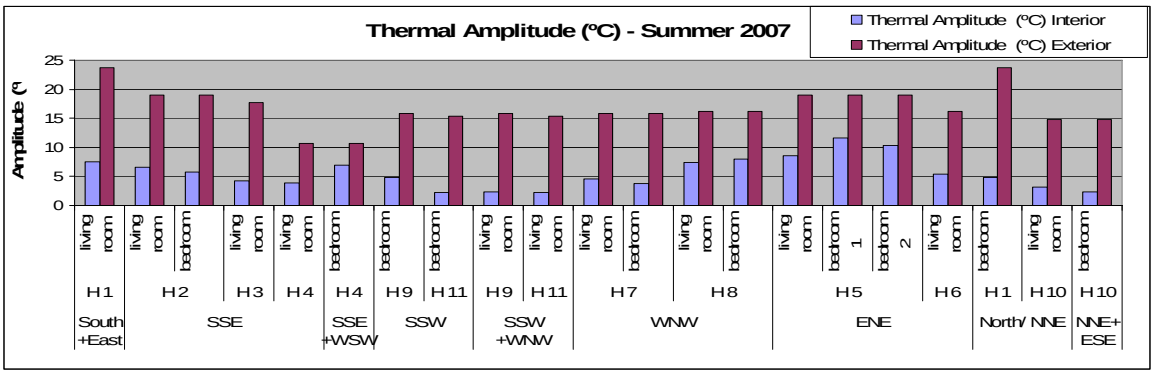

Fig. 8. Thermal amplitude for the different compartments – summer 2007.

The exterior thermal amplitude varied practically between 15ºC and 25ºC in the different monitoring periods. The greatest external amplitude was obtained during the measurements performed in dwelling 1 (23ºC), while the lowest was obtained during the measurements performed in dwelling 4 (10ºC).

The greatest interior thermal amplitudes were obtained during the measurements performed in the compartments that kept the windows open during a good part of the time, even during daytime, like: the compartments in dwelling 5 (east), living room of dwelling 8 (west) and the bedroom in dwelling 4. Generally, the interior thermal amplitude for most of the compartments was of approximately equal to 5ºC. Most compartments of the housing units 7, 8, 9, 10 and 11 present low thermal amplitude values, on average 3,5ºC. These flats belong to a set of buildings that have exterior solar blind-type protections that permit greater flexibility, control and adaptation to the exterior conditions.

5.2. Winter measurements

Concerning the external conditions the monitoring periods that presented lower temperatures during more time were the ones corresponding to the measurements made in housing units1a, 2, 4, 5 and 9, during approximately 5% of the time the temperatures were below 5ºC and in approximately 30%-40% of the time the temperatures were between 5ºC and 10ºC. The other periods had temperatures between 5ºC and 10ºC approximately 20%-25% of the time.

All the different monitoring, the exterior temperature was most of the time between 10ºC and 15ºC, near or than 50% of the time. The corresponding measurement periods in the housing units 7, 8, 10 and 11 were the ones to show temperatures between 10ºC and 15ºC during comparatively more time than the others, approximately 65% of the time. For the different monitoring periods the temperature was between 15ºC and 20ºC in approximately 10%-20% of the time. Only the measurements in housing units1b, 8 and 11b resulted in exterior temperatures between 20ºC and 25ºC.

None of the compartments monitored during the 2007-2008 winter months presented interior temperatures below 15ºC. However, some had temperatures below 18ºC. The only apartment with glazing areas practically to the south that had temperatures below 18ºC was dwelling 9 (7%-20% of the time), because it was closed and unoccupied during some time (windows closed and blinds lowered). The other housing units that had temperatures below 18ºC were dwelling 8 (west) in 16%-26%of the time, and dwelling 5 (east) in 0,5%-4% of the time.

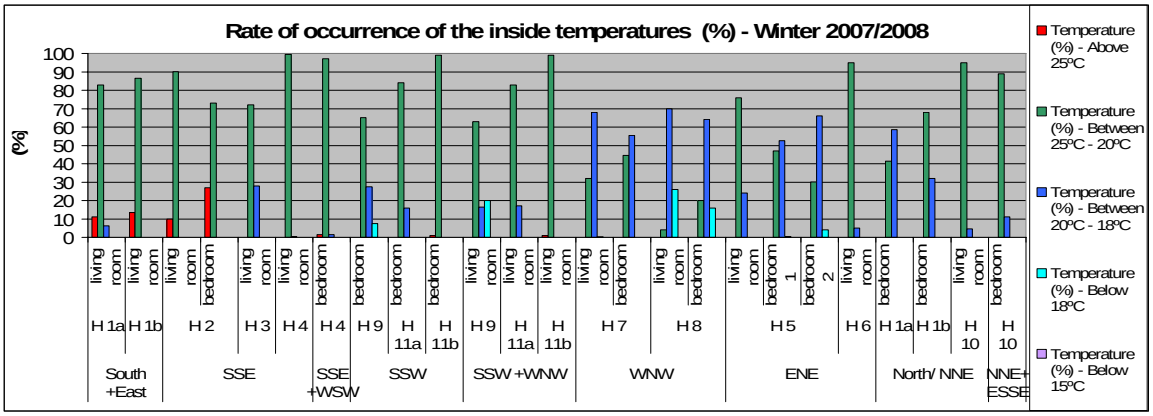

Fig. 9. Rate of occurrence of the inside temperatures for the different compartments - winter 2007-2008.

The compartments of the housing units with glazing areas oriented practically west and east were the ones that presented interior temperatures between 18ºCand 20ºC during more time, approximately between 55% and 70% of the time. Only some compartments with glazing areas practically to the south presented temperatures between 18ºC and 20ºC, these were housing units1a, 3, 9 and 11a, in 6% to 26% of the time. The compartment of dwelling 1 with glassed area to the north, presented temperatures between 18ºC and 20ºC in 32%-52% of the time.

It was the dwellings with glazing areas oriented to the south, SSE and SSW that presented the temperatures between 20ºC and 25ºC for more time, on the average 85% of time; while the west presented between 4% and 45% of the time. In some compartments with glazing areas practically to the south (S, SSE, SSW) temperatures above 25ºC were obtained even in the cold season; these were housing units: 1 (11%-14% of the time), 2 (10%-27% of the time), 4 and 11 (1-1,5% of the time).

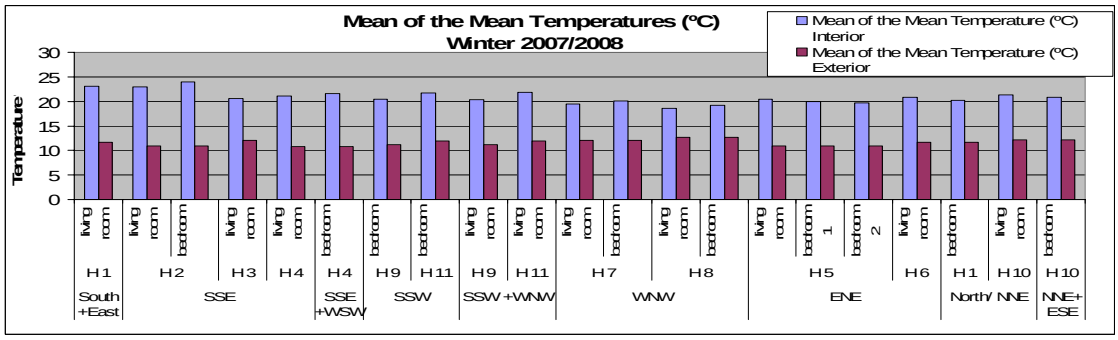

Fig. 10. Mean of the mean temperatures for the different compartments – winter 2007-2008

Mean of the mean temperatures: The average of the exterior average temperatures was 11,5ºC during the different monitoring periods, while the average of the interior average temperatures in the different monitored compartments was approximately 21ºC. For the compartments with glazing areas practically to the south, the average of the average temperatures was approximately 22ºC, while for the compartments with glazing areas practically to the east and west was approximately 19,8ºC.

Mean of the maximum temperatures: The average of the maximum exterior temperatures was approximately 15ºC during the different monitoring periods. For the compartments with glazing areas practically to the south the average of the maximum temperatures was approximately 23ºC, being that for dwelling 1 was approximately 25ºC and for dwelling 2 25ºC-27ºC. Some housing units presented an average of the maximum temperature below or very close to 20ºC, these were mainly the compartments with glazing areas oriented to the west, east and north. In dwelling 1, while a living room compartment (façade S +E) presented an average of the maximum temperature

of 25ºC, the bedroom (façade north) presented an average of 20ºC. When comparing dwelling 2 with 5 (similar exterior conditions and average of the maximum temperatures), dwelling 2 presented an average of the maximum temperatures higher than dwelling 5 of 4ºC -5ºC.

Mean of the minimum temperatures: The average of the exterior minimum temperatures was 8-9ºC in the different monitoring periods. Most of the studied compartments with glazing areas practically to the south presented an average of the minimum temperatures greater than 20ºC (in general close to 21ºC), the west and east housing units had averages lower than 19ºC. In dwelling 1, the living room had an average of the minimum temperature of 22ºC, while the bedroom 19,7ºC.

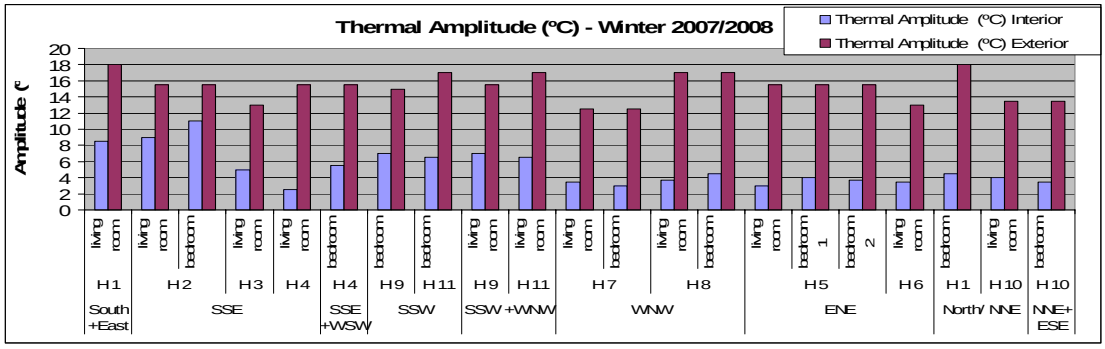

Fig.11. Thermal amplitude for the different compartments – winter 2007-2008.

The exterior thermal amplitude practically varied between 13ºC and 18ºC in the different monitoring periods. The largest interior thermal amplitude was obtained in the measurements performed in housing units 8 and 11, while the lowest was obtained during the measurements in dwelling 7. The largest interior thermal amplitudes were obtained during the measurements in the compartments with glazing areas oriented practically to the south, amplitudes varying between 5ºC and 11ºC. Only dwelling 4 had amplitude of 2,5ºC, and this due to a heating system type (programmed to maintain temperature of 22 ° C). In the remaining monitored compartments (with glazing areas practically to the east, west and north) the thermal amplitudes were between 3ºC e 4,5ºC.

6. Conclusions

This paper shows the results obtained in a group of building apartments block during a monitoring campaign (2007-2008), in summer and winter, in order to study the internal thermal comfort in building with similar characteristics (high percentage of glazing area 75% of façade area), that have been recently built in Lisbon. The results shows for summer period that all dwellings presented mean temperature above 25ºC, close to 80% - 90% of the time the housing units that have large south facing glazing areas reached temperatures above 27°C. In winter monitoring period the registered mean temperatures was 21°C. It was also verified that: the apartments with large south facing glazing areas has temperatures above 23°C, and on certain occasions even reach 28°C. The fractions with large east and west facing glazing areas showed mean temperatures normally between 19°C and 21°C (the minimum temperature observed was equal to 17°C). These very high temperature values in winter can be explained by the existence large glazing areas and the adaptation of high insulated levels for the opaque envelope. With the inquiry distributed among the occupants it was possible to confirm that the conventional heating systems were switched on often. The results shows also that in most of the apartments are uncomfortable conditions in both summer and winter seasons if for comfort temperature are considered 25ºC and 20ºC, respectively. In these kinds of buildings it is necessary to take much care with the glazing areas and solar protection. The relative humidity was normally between 35% and 65% in the monitored housing units for both seasons.

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