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Thermal comfort in the Modern Movement — Evaluating the winter behavior of a housing building in Porto, Portugal

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Abstract

This study aims to examine how the original construction systems implemented in a modern movement apartment building affect its winter thermal comfort. The importance of analyzing the avant-garde and distinctive buildings of this period is linked to the need to define appropriate and specific strategies for their reuse, maintenance and restoration, in order to assess how these buildings can maintain their original integrity and identity. In this study, thermal measurements and simulations were carried out to check whether the indoor conditions meet today's standards considering an adaptive comfort model. We can conclude that thermal passive comfort is essential to the concept of architectural space, shape and distribution of functions developed by the designers of our case study building. This research provides the basis for defining respectful restoration interventions in architectural heritage of the Modern Movement. It also tries to show that contemporary needs and requirements regarding thermal comfort can be achieved with the occupancy of the dwellings with minimal adjustments and interventions in the existing constructive systems.

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Keywords: Comfort; Edifício Lino; Modern movement; Intervention; Adaptation

1. Introduction

This article is based on the results of a study that analyzed the architectural principles [1], materiality and constructive systems of an apartment building called Edifício Lino, built in 1953, to verify how it compares to the current thermal comfort expectations during the heating season [2]. The building was designed by Arménio Losa and Cassiano Barbosa, architects who played a leading role in implementing the architectural language of Modernism in Portugal. The analysis, supported by in situ measurements, aims to establish fundamental principles and strategies for minimal and optimized intervention in the restoration and maintenance of buildings. This intervention had to be

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able to preserve the quality and character of the buildings and spaces of that period, while accepting a harmonious combination of new uses and responding to contemporary comfort requirements [3].

Luis Vital proclaims that "the notion of comfort appears clearly assumed as a modern characteristic. (...) Modern comfort is considered an architectural quality that should be implemented to the furniture, certain materials, finishes, efficient mechanization of the kitchen and bathroom, and (...) elements that control the ambiance" [4]. In his opinion the architecture of the Modern Movement aims the wellbeing of men through the conception and treatment of Architectural spaces, Green spaces and Light.

From a study of two iconic pieces of Modern Movement architecture designed by Le Corbusier in the 1950s, the Millowners Association (Ahmedabad, India) and the House of Brazil (Paris, France); Ruiz and Siret propose "modern architecture as the carrier that disseminates a common scientific and political positioning on the thermal qualities of the living environments for the Homme Nouveau", concluding that modern architecture influenced "the early development of the notion of thermal comfort and the integration of environmental techniques in the architectural design" [5].

If the designers of our case study were "enthusiastic" defenders of the ideas of the Modern Movement, then the incorporation of comfort qualities should have been incorporated into their architecture [6]. In fact, reading their texts, details and project drawings, we realized that there is a common constructive vocabulary that runs through all their work. This shows the importance of passive systems in controlling the thermal comfort of dwellings. Some of the premises recurring in Losa and Cassiano's constructive lexicon are finding the optimal sun orientation [7], directly related to the programmatic organization of the dwelling; building envelope design to improve the thermal performance of the dwelling; installing shading systems to control direct sunlight; window frame detailing to optimize interior insulation, condensation and ventilation control; cross ventilation and daylighting in all interior spaces.

With the current study, we aim to verify and measure whether these qualities are still present in the building and, most importantly, to confirm that the values for thermal comfort in winter are in line with today's standards.

2. Thermal comfort evaluation — "In situ"

After a constructive analysis and the calculation of the thermal transmittance U (W/m^2 °C) carried out, we realized that these does not correspond to the minimum required values, although the calculated useful thermal mass was 466 kg/m^2, thus allowing a strong thermal inertia, what is a positive aspect in a temperate climate [1]. According to the dispatch of the diary of the Portuguese republic n.º 15793-K/2013 three classes of thermal inertia are defined, weak, medium and strong; here the values that determine the three classes are: $It < 150$, $150 \leq It \leq 400$ and $It > 400$ respectively. Comfort measurements were carried out on site with the expectation that these may demonstrate that the living conditions of this building are good or at least acceptable. These measurements also allowed the validation of the conditions considered in the thermal simulations that were intended to be carried out.

Experimental assessment of building hygrothermal performance requires monitoring during cooling and heating seasons to obtain important summer and winter data for understanding building thermal performance. The measurements for the cooling season have been carried out and presented in a previous article by the authors, where the results of the 'in situ' measurements, complemented by simulations, allow the realization of the operating temperature through data acquisition and simulation. This allows the building to be in category I of adaptive and comfortable buildings (EN-16798 standard) in which the internal temperature difference throughout the day should not exceed 5 °C [1].

2.1. Measurements in heating season

Two scenarios were used for field measurements, one with shutters closed (scenario 1) and one with shutters open (scenario 2). During the monitoring process, the opening of the window has not changed and has been closed. It is also important to mention that the apartment is unoccupied, so there are no internal gains. Temperature and relative humidity measurements were performed using a portable data logger device. These parameters are necessary to evaluate the operating temperature. The results presented in this study were obtained during a 7-day measurement campaign carried out in buildings between 5 and 12 January 2021, representing a heating period.

- Air Temperature

Measurements carried out in Scenario 1 during the heating period determined that the fluctuations in the interior temperature were much smaller than the fluctuations in the exterior temperature. The highest and lowest temperatures during this period were 9.4 °C and 7.8 °C inside the apartment, and 9.8 °C and 0.4 °C outside, indicating a difference of 9.4 °C between the temperature peaks of 1,6 °C indoors and outdoors. The values recorded inside are due to the absence of direct sunlight as shutters were closed during the day. The façade design allows a small warm up during the day, and the heavy elements of the floor, walls and ceiling ensured thermal mass. Heat loss at night is also reduced, not only due to the high thermal mass, but also due to the external protection of the louvers, thus balancing the extremes. It is also important to compare the 0.4 °C difference between the outdoor and indoor maximum temperature peaks, note that the outdoor temperature exceeds the measured indoor temperature, which is not the most favorable comfort situation, but a difference of at least 7,4 °C, which is relevant, because while there is no solar gain, losses are also lower, and the correct use of blinds (closing only at night) can permit favorable conditions. Scenario 1 is also bad for lighting comfort because no sun light enters the room.

In scenario 2, the indoor temperature varies greatly during the heating season, reaching 11 °C, with the highest and lowest temperatures being 19.5 °C and 8.5 °C, respectively. This variation is due to solar gain during the day, with insolation covering all south-facing spaces from sunrise to sunset, allowing greater solar gain even with higher minimum temperatures compared to Scenario 1 for the same season. The heat accumulated on the walls, roof and floor during the day releases the stored heat at night and increases the minimum temperature due to strong thermal inertia. However, when the shutters are opened at night, the heat loss through the glass windows will be faster.

Compared with the outdoor area, the smoothness of the façade design is better when the maximum indoor–outdoor temperature difference is 9.7 °C and the minimum temperature is 8.1 °C, where the temperature is quite low considering the lack of outdoor protection measures. As with Scenario 1, a favorable scenario can also be obtained in the same time interval if the shutters are used correctly.

• Relative Humidity

The relative humidity results obtained in the heating station of Scenario 1 according to EN 15251:2007 standard recorded a maximum value of 64.3 and 48.5% in sequence, which confirms that these data conform to and are close to class II, confirming that it is in the range of 25% to 60%. This relative humidity check is relevant because despite seasons of increased precipitation and associated humidity, the behavior of buildings in temperate climate does not affect people's comfort in terms of air quality, as well as the durability of materials and equipment present indoors.

In Scenario 2, it again allows to verify that the obtained values comply with EN 15251:2007, which corresponds not only to category III of the case study, but also to category II, the normal level expectations, recommended for new buildings and renovations. The values collected, the maximum and minimum values are 55.7 and 27.5% respectively, and the average value is 44.2%, which is due to the high temperature measured indoors, the relative humidity in the room is even lower due to the sunshine during the day, the shutters are open, and the relative humidity in the room is even lower considering the maximum outdoor Humidity 90.8% (even if it is not raining) and at least 30%. These interior values also give us reason to expect that the correct use of blinds and windows at this time of year will ensure optimum thermal comfort as well as optimum acoustic and natural lighting conditions.

• Operating Temperature

In order to understand the thermal comfort of the dwelling, the operating temperature during the heating season was evaluated using Scenarios 1 and 2 given above. Under comfort conditions as defined in EN 16798:2019. The graphs in Figs. 1 and 2 were generated using the online tool Center for the Built Environment — Thermal Comfort Tool [8] using the operating temperature of an occupant sitting in the middle of the compartment wearing winter clothes (1 clo). Since all windows are both closed and the mean radiant temperature is equal to the air temperature, so the indoor air velocity is zero.

Interpreting Fig. 1, the non-compliance with EN-16798 in Scenario 1 is resolved because the values of ambient temperature and mean radiant temperature are low and equal, since the shutters are closed and there is no radiation in the air the asymmetry is zero. In this case, certain things happen only due to the absence and lack of sunlight in the building. Therefore, the collected values do not fall into any comfort category of the standard.

From the analysis of Fig. 2, based on Scenario 2, it can be shown that during the heating season, it complies with category II of EN-16798 as the temperature increases, however, due to the absence of shutters, the fluctuating temperature of operation is higher. The average difference between the minimum internal operating temperatures was 8.3 °C, making it impossible to meet the standard at these lower temperatures. Even taking into account that the average difference between the extremes of the average operating temperature and the outdoor temperature was 11.2 °C at maximum and 8.8 °C at minimum.

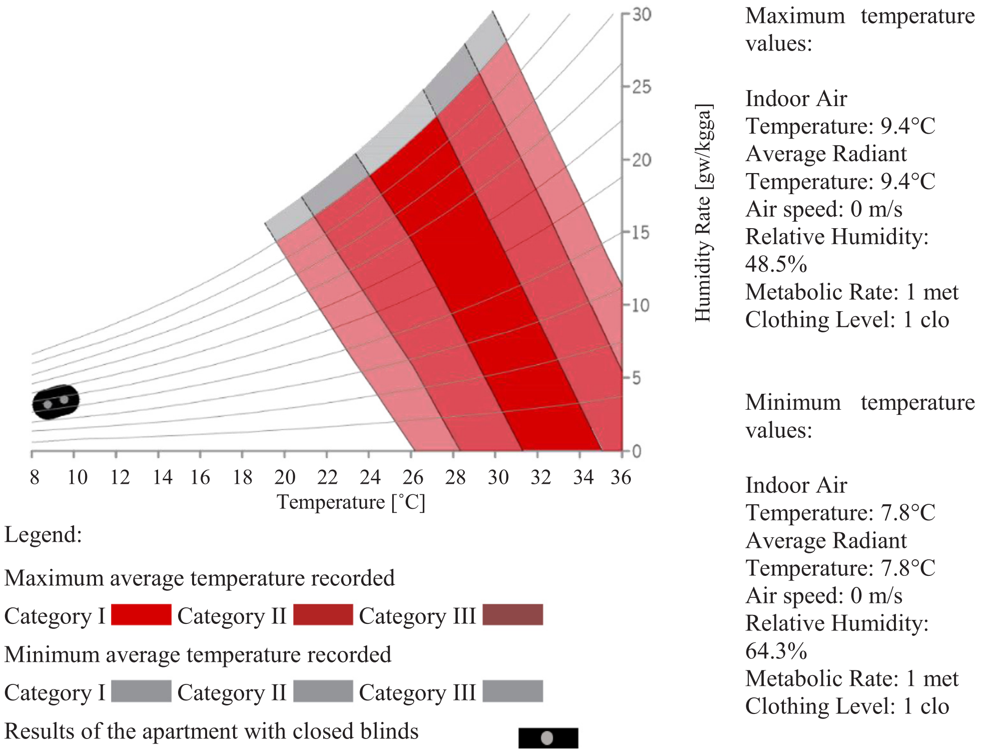

Fig. 1. Evaluation of the comfort in the apartment with the blinds closed, from 05 to 12 January.

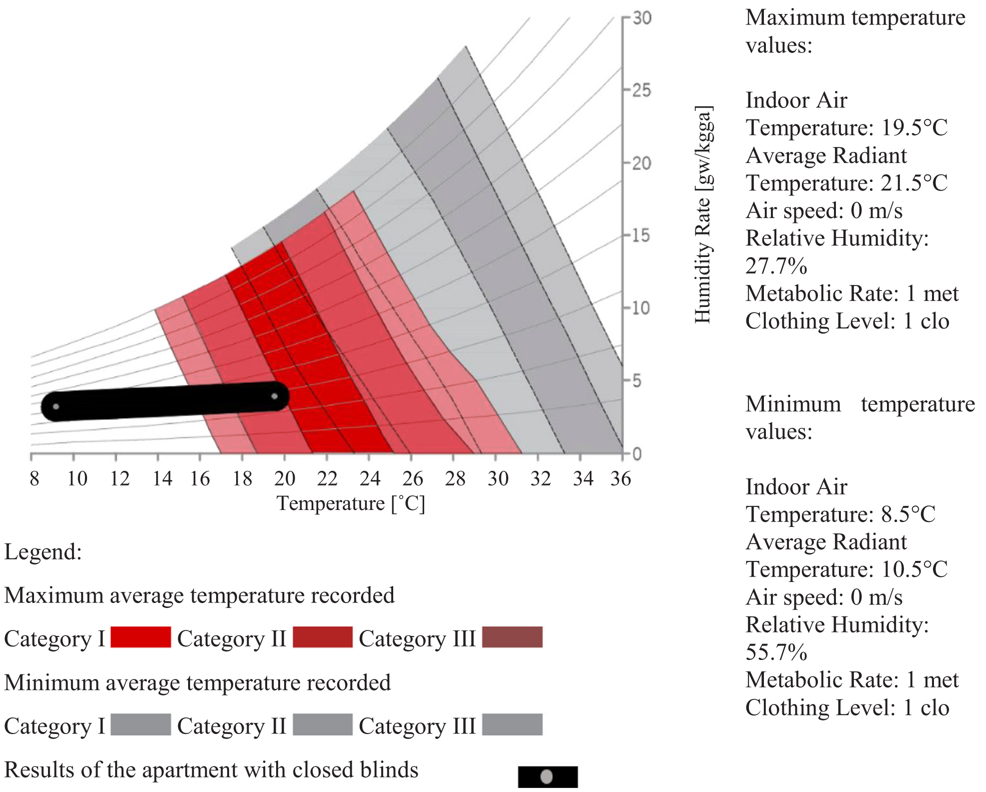

Fig. 2. Evaluation of the comfort in the apartment with the blinds open, from 05 to 12 January.

3. Thermal comfort simulation

Simulation tools are important for testing things that cannot currently be verified in the field. Since the building is currently unoccupied and it is difficult to monitor occupancy in a representative and controlled manner, we decided to simulate occupancy in the building. This makes possible to take into account the constant heat exchange between the occupant and the room, which contributes to the heating of the room, as well as household appliances such as televisions and lamps, which constitute the usual occupancy [9–12]. It also allows consideration of the operation of the shutters, as well as the restoration of all window frames and shutters to their original condition. In a previous study on the summer thermal performance of this building [1], simulations showed that it is possible to improve the thermal comfort of the building in summer under normal occupancy and daily use of the dwelling.

DesignBuilder is a graphical interface for the EnergyPlus (US Department of Energy) energy simulation method. DesignBuilder provides several simplified options for the early stages of a project, as well as more complex options that allow for more detailed analysis of the energy model. EnergyPlus is the U.S. Department of Energy's building energy simulation program for modeling building heating, cooling, lighting, ventilation, and other energy flows. It builds on the most popular features and capabilities of BLAST and DOE-2, and includes many other innovative simulation features.

For simulation in the DesignBuilder interface, the typological features of the building were inserted. The results presented and analyzed are from one of the second-floor apartments, where the floor and ceiling have no heat loss and are therefore in an ideal condition. In addition to type models, all materials that are part of the residential building system are inserted, as well as a framework for characterization in terms of existing materials. The operating schedule of the windows, both ventilation and shading, has been taken into account. For verification, it was necessary to find the day with the highest and lowest outdoor temperature: 9.8 and 4.4 °C, respectively, which have a similar ΔT to the temperature measured in situ. The search returns January 4, 2003. After validating the measurements, it was decided to run the simulation for the week of January 4–12, a typical winter week. This procedure allowed to simulate the operative temperature and the relative humidity necessary to assess adaptive comfort according to EN-16798.

Through the analysis of Fig. 3, with an ideal occupation scenario, the apartment is in Category II at the maximum simulated temperature, and in Category III at the minimum temperature. The EN-16798 standard does not consider outdoor temperature values below 10 °C, and it is necessary, according to the standard, to use the average outdoor

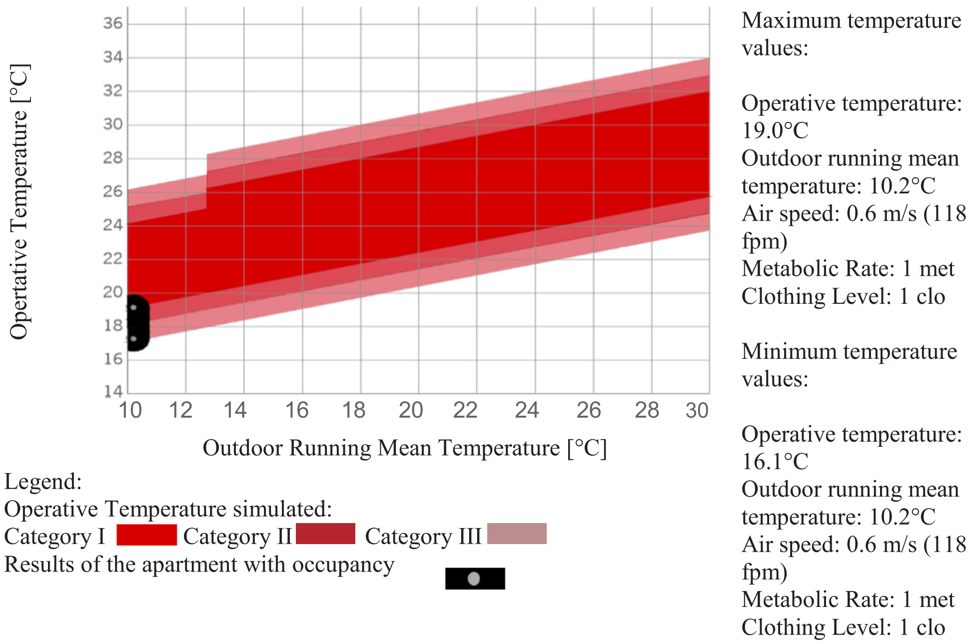

Fig. 3. Evaluation of the simulated comfort in the apartment with occupation, from 05 to 12 January. EN-16798.

temperature and assign it to the registered temperatures. The maximum operative temperature was 19 °C and the minimum 16.1 °C with the outdoor running mean temperature of 10.2 °C. The norm is partially fulfilled for the maximum temperature within Category I, with the minimum temperature close to the acceptable level of expectation of Category III.

It can be emphasized that the only intervention was the inclusion of people, the experience and adaptation of these to the characteristics of the apartment. The number of pieces of clothing worn is also an important factor, since the inclusion of a larger number of pieces directly influences the thermal comfort [13,14] due to the adaptation [15,16] that is made to the building, this harmony being fundamental to preserve the validity of the study. Proving also the functioning of the facade to take advantage of the solar incidence in the sunshine hours and the protection of the blinds to the heat losses during night time. A strategy for future building reuse based on minimal restoration interventions is to reactivate and maintain the passive thermal control systems implemented in the original project and to allow the occupants to manage them properly. However, in order to define this approach, it is necessary to know and describe all the pre-existing constructive systems, fabrics and materials that make up the building's structure, so that a full assessment of the type of action required must utilize them effectively. We believe that the main goal of restoration should be to preserve the original values of the building, such as identity and integrity, and to guarantee the comfort of the occupants of these spaces [1,17,18].

4. Conclusions

Mainly due to the fact that our case, Edifício Lino, has been abandoned for a long time without maintenance, with serious anomalies in the façade and window frames, the results of the "in situ" measurements showed a poor thermal performance in winter. Furthermore, due to being unoccupied, measurements of buildings do not take into account the impacts associated with human occupancy and use of their spaces and systems.

The results of the simulations carried out, considering a simple renovation of the existing building systems, occupancy of the building and the correct use of existing window shutters, show that we can easily achieve thermal comfort in winter. This is ensured by simulating occupancy scenarios that allow the shutters to be opened during the day and closed at night, allowing the apartments to have a higher and stable temperature.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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