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Monitoring the thermal comfort of a multifamily housing building from the Modern Movement period

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Abstract: This paper presents the thermal comfort monitoring of a heritage multifamily housing building from the Modern Movement period. The objective of this analysis is related to the need of defining appropriate strategies for (re)use, maintenance and possible intervention in heritage buildings of this period in order to fulfil contemporary expectations of thermal comfort, but still maintaining its identity. In situ measurements were carried out to verify the passive thermal response of this now unoccupied building designed by Architects Armenio Losa and Cassiano Barbosa. Good solar orientation, wood window frames incorporating ventilation and shading systems, insulation and water-proofing were part of the construction lexicon of these architects that were applied in this building. From the analysis carried out to the original design, it can be concluded that thermal passive comfort was already intrinsic and appeared as a central concern. Our expectation is that, minimum adjustments and repairs in the already integrated systems, combined with occupancy, can be enough to fulfil contemporary expectations in users' thermal comfort, considering the Adaptive Comfort Model. If future intervention reveals necessary, we believe that this study can contribute to adequately decide the most appropriate strategies: if functional refurbishment replacement of elements or simple repair.

Keywords: Thermal Comfort; Modern Movement; Heritage Intervention; Adaptation; Functional analysis

1. Introduction

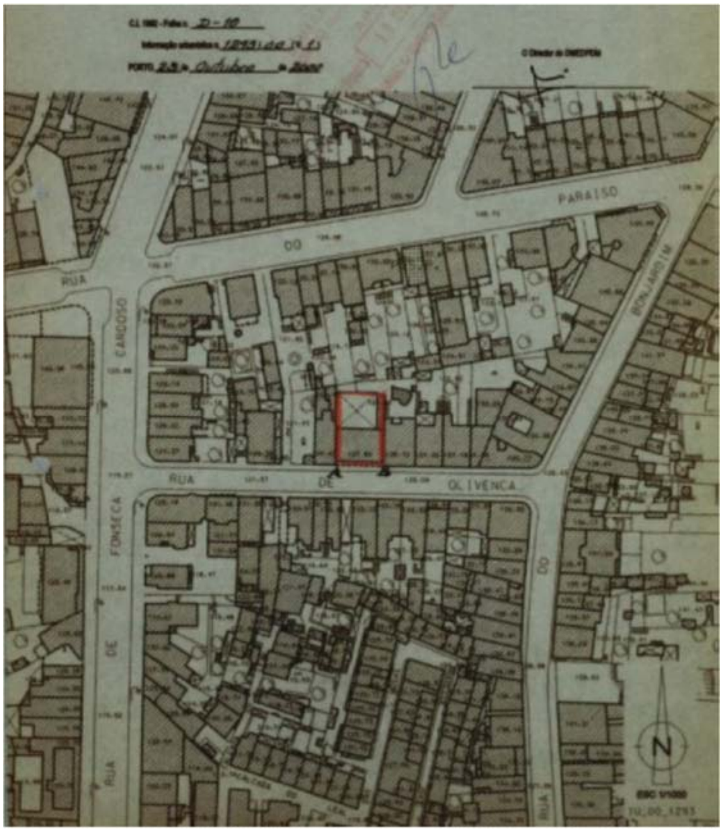
The building here analyzed was built between 1951 and 1954 in Porto, Portugal, and was designed by Arménio Losa and Cassiano Barbosa, two architects that had a leading role in the implementation of the Modern Movement architecture in Portugal. This building, known as "Edifício Lino", was evaluated in terms of its comfort parameters [1,2]. This analysis is supported by "in situ" measurements, aiming to create the fundamental principles and a strategy for a minimal and optimized intervention. As the building is unoccupied and the operation of existing windows and respective blinds are difficult to monitor, we considered two scenarios, with blinds closed and with blinds open. The use of computer simulations will be also needed in order to consider dynamic schedules of opening and closing the blinds and window frames [3]. One of the objectives of this monitoring is to validate simulations and create the fundamental basis for the restoration or refurbishment intervention to be carried out. This intervention shall be attentive to the temporal, spatial and tectonic peculiarities that define the heritage buildings of this period, but at the same time it should accept the need of harmoniously incorporate the new uses and expectations.

“*The intervention in modern heritage buildings is not simple, the whole process has to be very careful with the questions of materiality, authenticity, it is an architecture that has a very own spatiality that often does not accept great changes.*” [4]

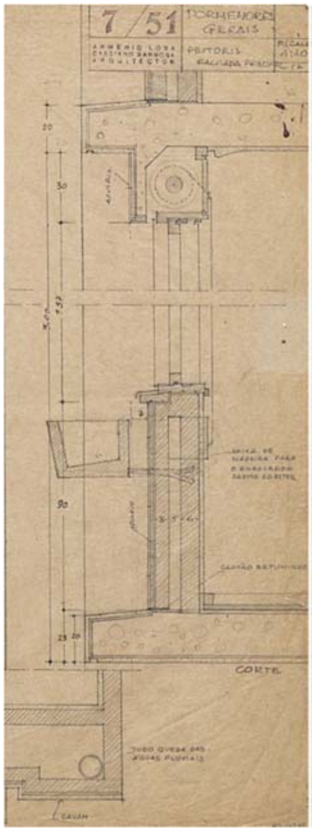
The Modern Movement architecture has always searched for the well-being and the comfort of man [5]. Lima [6] said “*work, body and mind culture*” are the principles of this architecture. Vital adds "*The notion of comfort appears as a clearly modern feature (...) modern comfort is considered as an architectural quality, and it is necessary to attribute it to furniture, certain finishes, efficient mechanization of the kitchen and bathroom, and (..) elements that control the environment.*" [7]

This notion of incorporating comfort as intrinsic quality of the architecture was always present on the works of Losa and Barbosa. Prior to any intervention we must verify how these materials and qualities behaved over time and, above all, confirm that the comfort parameters (thermal, natural light and noise) of these buildings are acceptable for contemporary standards. As Ana Tostões argues “*the current regulations on safety, energy performance and environmental comfort put reuse actions in pair with the requirements necessary for the construction of new buildings, often calling into question a qualified refurbishment. Thus, one of the objectives of the intervention will have to go through the meeting of a specific lexicon, which considers the character of the built along with the mutations necessary for the experience of space.*” [8]

With the measurements carried out in situ we expect to verify how the mechanisms designed in order to respond to the demand for comfort, imposed by the architects of the Edifício Lino [9, 10] correspond to contemporary expectations of thermal comfort and which changes will have to be implemented. Good solar orientation, wood window frames incorporating ventilation and shading systems, insulation and water-proofing were part of the construction lexicon applied in all the works of these authors. The future intervention should be able to decide which strategies to implement that may optimize these systems, whether through changes, replacements of elements or simple repair. The characterization of all systems and materials that integrate Edifício Lino is fundamental for a complete evaluation of the type of actions to be taken for its efficient use, assuming that the main objective is to maintain identity and integrity of the building. For this and as shown in Figure 1, it is necessary to understand the historical framework of the building regarding its implantation, design and details.



(a)



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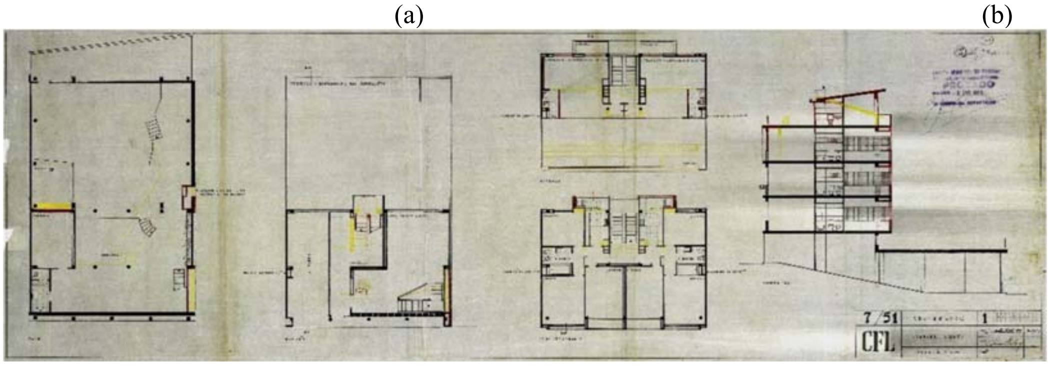


(c)

Figure 1. Edifício Lino, Implantation (a), detail of façade section (b) plans and section drawings (c) from the construction period (1951-1954). Adapted from [9].

2. Climate context and thermal characterization of the building

The climatic framework of Porto is important to understand the response of the monitored apartments in Edifício Lino. Porto presents significantly more heating needs than cooling needs, what can be seen in Figure 2. For reducing the heating needs, the solar orientation of living areas to south is an important issue as these allow solar passive gains through glazed areas of the facade. For reducing the cooling needs, shading and night cooling ventilation are the most important aspects to consider. The use of thermal insulation in walls is also a very significant aspect. Figures 3 and 4 show the type of envelope elements in which the Thermal Transmittance should be considered: the walls of the north and south facades (in red), the respective windows because they are in contact with the exterior and the wall between the apartment and the common staircases of the building (in yellow). This is because it is a space in direct contact with outside, with fixed windows. It should be noted that the envelope elements marked in green, when in contact with spaces that are also interior, are spaces without thermal requirements. It is important to emphasize that in the walls between apartments, the architects kept the wall with two rows of bricks and air gap between them, for sound insulation; while on the east wall of the building that is in contact with another collective housing, without thermal requirements, they only applied a row of bricks, demonstrating sensitivity to an efficient resources' management.

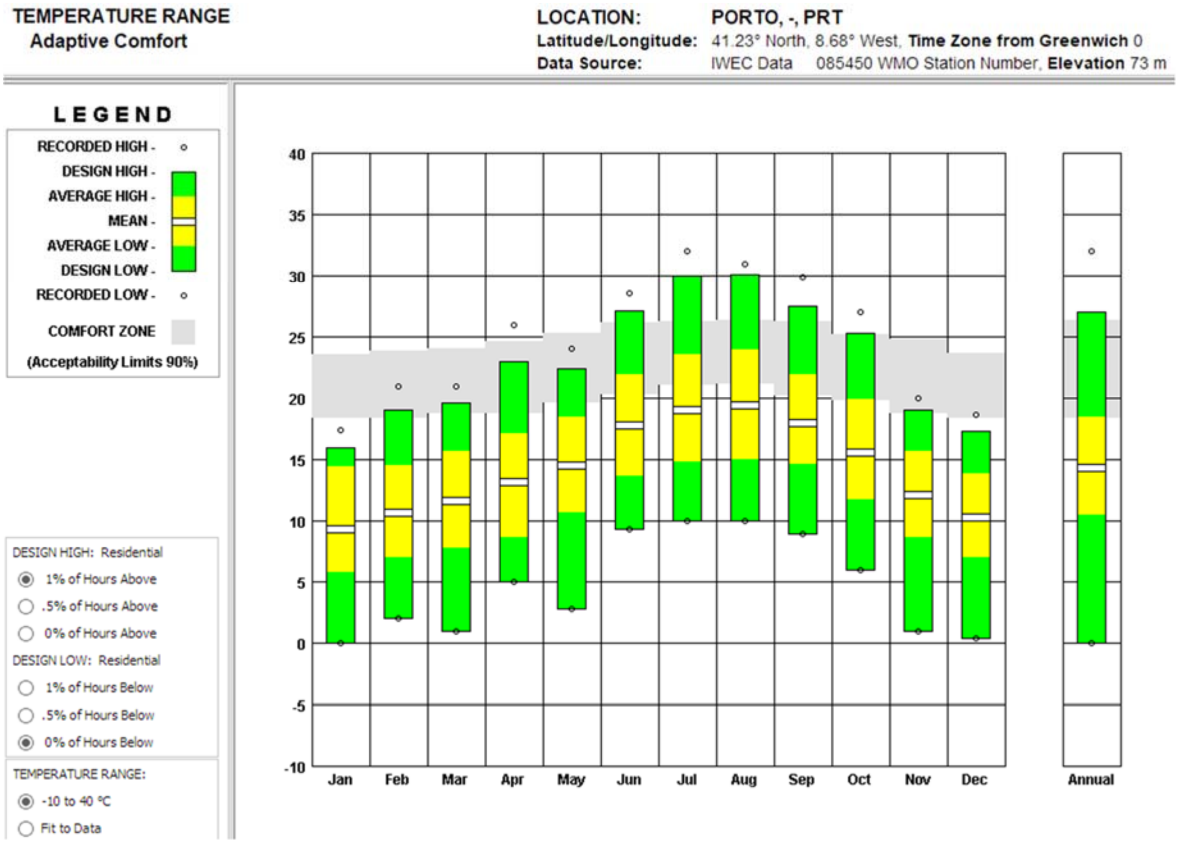


Figure 2. Average temperatures in Porto and its compliance with Adaptive Comfort Model range (graphic produced by the third author using Climate Consultant software).

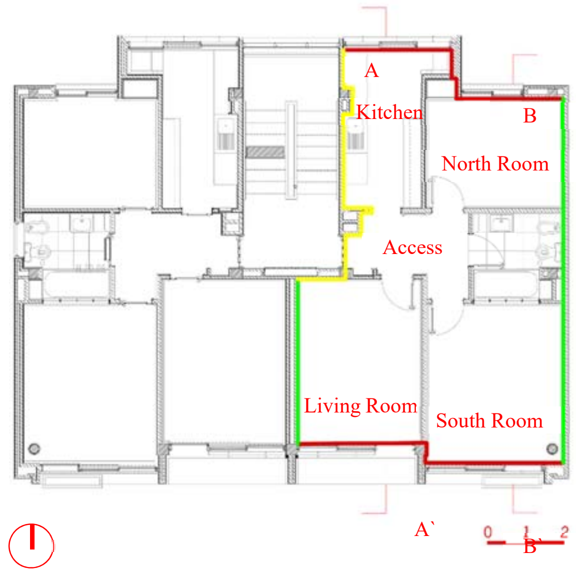


Figure 3. Plan with envelope elements.

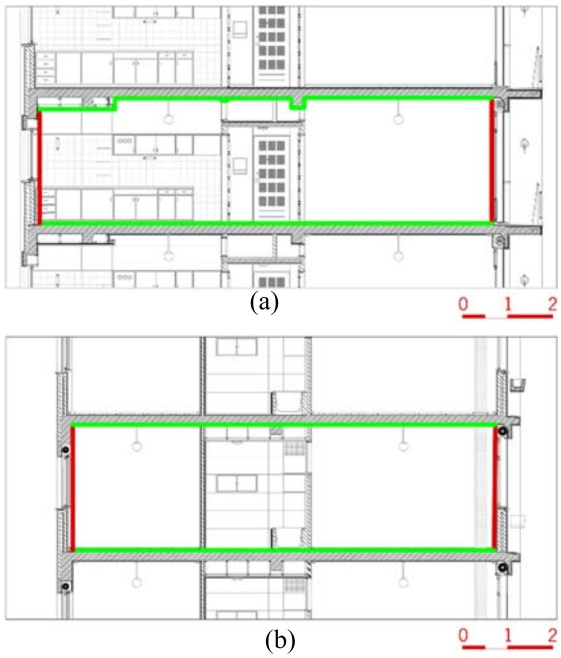


Figure 4. Section [AA´] (a) and Section [BB`] (b) respectively with envelope elements.

2.1. Analysis of Results

The calculation made and presented to the different building elements of the apartment under study, reveals that none of these meets the thermal insulation requirements of Ordinance No. 379-A/2015 [10]. The north facade where the kitchen and the north bedroom are located, and the south facade (Figure 5) of the living room and the south bedroom, being vertical opaque elements, present an U-value of 1.22 (W/m².ºC) which mean that the minimum Uref of 0.40 (W/m².ºC) is not achieved. The same applies to elements in contact with non-useful spaces such as the dividing wall between the apartment and the vertical access that exceed the Uref value of 0.70 (W/m².ºC) for this type of elements, i.e. also do not meet this requirement.

The glazed areas also do not meet, given the value taken from the ITE50 [11] for simple 4mm glazed areas with wooden frames, of 5.1 (W/m².ºC), much higher than the Uref requirement of 2.40 (W/m².ºC).

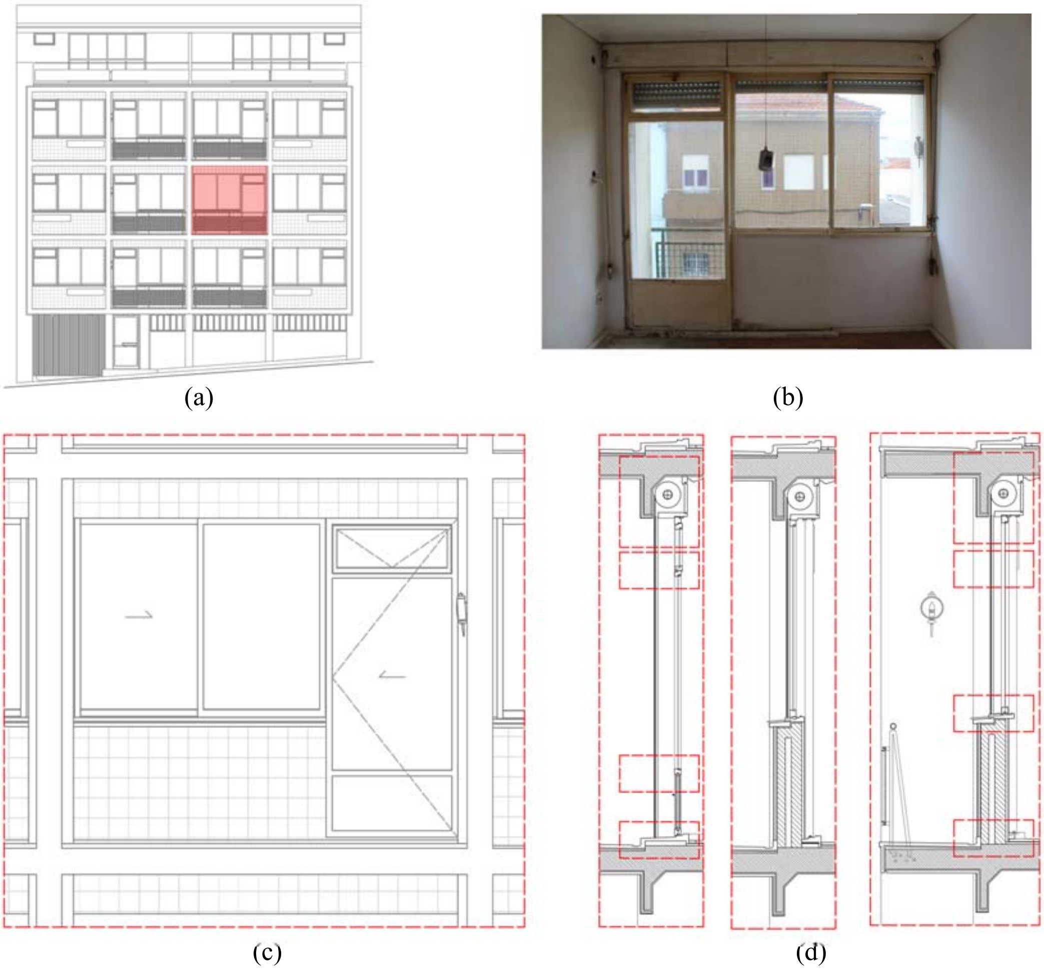


Figure 5. Constructive details of the living room: (a) South façade (b) Photo of the interior of the living room (c) Living Room facade 1:50 (d) Vertical Sections 1:50.

3. Thermal comfort evaluation - "In situ"

After the results obtained in the constructive analysis and the calculation of the U value, realizing that these doesn't correspond to the minimum required values, the comfort measurements were carried out on site in order to verify what are the real living conditions of this building. "Temperature and humidity are the most important aspects of indoor environmental conditions (...) determine to a large extent the conditions of thermal comfort, due to the impact they have on several of the thermoregulation mechanisms of the human body." [12]

The experimental evaluation of the hygrothermal performance of the building requires monitoring during the cooling and heating season in order to obtain key summer and winter data to understand the thermal behavior of the building [13].

The Adaptive Thermal Comfort model described in EN 15251:2007 [14] and several studies [15-17] and the comfort conditions defined by EN 16798:2019 [18] were considered for this analysis.

3.1. Measurements in cooling season

Measurements of temperature and relative humidity were performed in situ by placing portable temperature and humidity monitoring dataloggers (Extech 42270), two indoor and one outdoor.

For the measurements, two scenarios were used (the portable dataloggers were installed in two different apartments located in the same floor of the building), one with all blinds closed (Scenario 1) and the other with all blinds open (Scenario 2). During the tests performed there were no changes in the opening of the glazed windows, which were always closed (Scenario 1) or open (Scenario 2). It is also important to mention that the apartments were without any occupancy and therefore without internal gains.

The results presented in this study were obtained in a measurement campaign carried out in the building, in a period of seven days, representative of the cooling station - May 21 to 29, 2020. Although this period doesn't correspond exactly to summer, it was an atypical week of spring with very high temperatures that corresponded to what was expected from a summer campaign.

These measurements highlight in Scenario 1 the maximum and minimum temperatures in this period, which inside the apartment were 24.8°C and 19.3°C, and outside, 34.8°C and 15.3°C, demonstrating that, while the difference of the indoor temperature peaks is 5.5°C, outside this value is 19.5°C. Comparing the temperature peaks of the interior with the outside, the difference between the maximum temperature of the outside and the inside is 10°C and between the minimums if of 4°C.

Although the thermal comfort results in the apartment are favourable in Scenario 1, they are not in line with the natural lighting comfort, because there is no entry of natural light into the spaces. In Scenario 2 the indoor temperatures present a slightly higher variation, of 7°C, and the maximum temperature in this period was 27.3°C, and a minimum of 20.3°C. Comparing the tests in the difference between the peaks, although smaller than in Scenario 1, are relevant due to solar gains during the day and heat losses through the openings at night. This difference between temperatures is 7.5°C and 5°C in relation to the maximum and minimum peak respectively. This proved that the studies and solar concerns of the architects in the building design, has a positive impact in the summer season. The results of this process allowed to understand how the design of the building responds in this solstice where the angle of solar height is greater. The angle of 70° used by Losa and Cassiano for the solar study of this building south façade [19], allows natural lighting during summer in the spaces, but mostly without direct incidence, avoiding the increase of the interior temperature.

For Relative Humidity, in both Scenarios they met EN 15251:2007 [14], which recommends for existing Category III buildings, a maximum and minimum value between 70 and 20%. In Scenario 2, the building reaches category II i.e. for refurbished buildings. The justification of these positive values is due to the high temperatures recorded outside that provide lower humidity, which consequently, inside the apartment, without any sun protection of the blinds, allowed the indoor temperature to increase and thereby reduce the relative humidity. It can be concluded that by the correct use of blinds, during this season, the values can even be optimized and provide the best comfort, whether thermal or natural lighting.

To better compare the hygrothermal comfort in the apartments, the Operative Temperature were thus evaluated during the cooling periods, with Scenarios 1 and 2 indicated above. This evaluation also allowed to understand the comfort conditions defined by EN 16798:2019

[18] in order to understand whether the apartments are within the parameters for category III (Pre-existing building category). Graphs shown on Figures 6 were plotted from the operative temperature for an occupant sitting in the center of the compartment in summer clothes (0.5 clo). The indoor air velocity was considered as zero due to all the windows being closed and the average radiant temperature equal to air temperature.

For these graphs, the temperature and maximum and minimum relative humidity of each day were evaluated, in order to establish an average weekly value of each factor, so that through the online tool CBE (Center for the Built Environment) [20] Thermal Comfort Tool, it was possible to verify that the values collected in the building are in accordance with the comfort zones of the EN-16798 [18] standard.

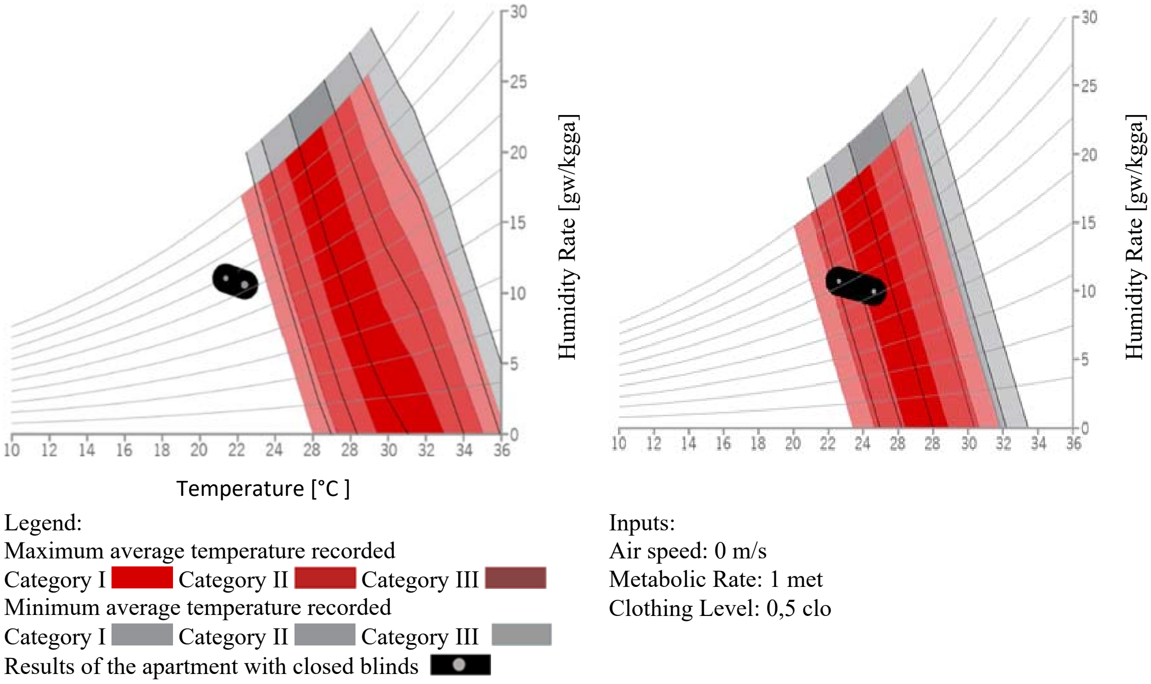


Figure 6. Evaluation of comfort in the apartment with blinds closed (left) and open (right), from 21 to 29 May.

Based on the interpretation of the Graphic presented in Figure 6, it is observed that it doesn't comply with the EN-16798 [18] standard in Scenario 1. However, this only happens due to the inoccupation of the building - although the collected values are outside the comfort range of the standard, it should be noted that the temperatures are lower, i.e. it meets the norm by excess, with no cooling needs. Easily in this season and conditions one could reach the values of the norm, just by opening the blinds, which was done in Scenario 2.

In Scenario 2 the operative temperature has a greater variation throughout the day, due to the opening of blinds, since with the simple glazing of 4 mm there are more solar gains during the day and consequent increase in the temperature of this surface and heat losses at night with the decrease of the temperature.

In Figure 7 it is possible to observe the great oscillation of the exterior temperature in relation to the interior operative temperature. This reveals the importance of thermal mass, because thermal discomfort is due to these high variations, if not absorbed.

Through the consultation of Graphic presented in Figure 8 allows verifying compliance with the EN-16798 [18] standard, throughout the week, between category III when it reaches the lowest operative temperature and category I on the days where they are higher, it is important to emphasize that the building, despite having the blinds open throughout the day, always remains within the comfort zone recommended by the standard.

3.1. Measurements in heating season

As for the summer measurements, the same procedures were followed for the winter, so the measurements of temperature and relative humidity were performed in situ and with the equipment placed in the same place. These are necessary to obtain the operating temperature. The results presented in this study were obtained in a measurement campaign carried out in the building, in a period of seven days, representative of the heating station 05 to 12 January 2021.

Through the measurements made in the heating season, in Scenario 1, it was found that, as in the cooling station in this situation, the variation of the indoor temperature is considerably less considering the oscillation of the outdoor temperature. The maximum and minimum temperatures in this period inside the apartment were 9.4˚C and 7.8˚C, and outside, they were 9.8˚C and 0.4˚C, demonstrating that the difference between the temperature peaks inside is 1.6˚C while outside it is 9.4˚C. The values recorded inside are due to the fact that during the day there are no direct solar gains due to the fact that the blinds are closed, which due to the solar slope and the facade design allowed a considerable increase in temperature during the day, as well as the thermal mass ensured by the heavy elements on the floors, walls and ceilings. At night the heat loss is also reduced, not only due to the high thermal mass, but also due to the outer protection of the blinds and therefore the balance between extremes. It is also important to compare the difference between the maximum outside and inside maximum temperature peaks of 0.4 ˚C, realizing that out-side the temperature surpassed that recorded inside, not being the most favorable situation of comfort, however the difference in minimum was 7.4˚C, which is relevant because although there are no solar gains, the losses are also smaller, and may precede a favorable scenario in the case of the correct use of the blinds. Scenario 1 is also disadvantageous for lighting comfort as there is no natural light entering the spaces.

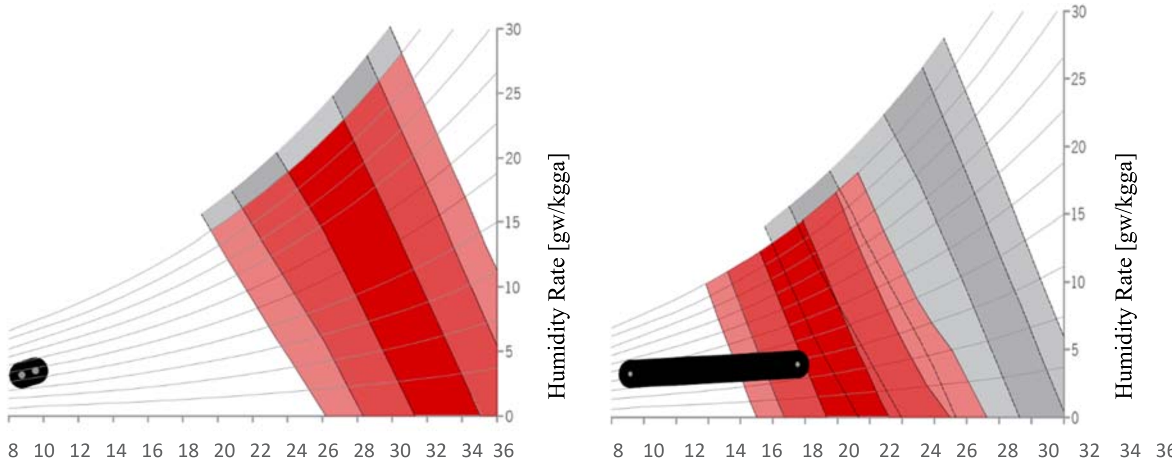
In Scenario 2, during the heating season, it was found that the indoor temperatures showed a greater variation, of 11˚C, with the maximum and minimum temperatures being 19.5 and 8.5˚C respectively. This variation is due to the solar gains during the day where the solar incidence covers all the spaces to the south from sunrise to sunset, allowing greater solar gains. Even in comparison with Scenario 1 of the same season, the minimum temperature is higher, due to the accumulation of heat during the day on the walls and roof and floor slabs, which at night release that heat and increases the minimum temperature, resulting from the strong thermal inertia. However, due to the fact that the blinds are open during the night, there is a greater acceleration in heat losses through the glazing.

In comparison with the exterior, the smooth functioning of the facade design is even better when the difference between the maximum temperatures of the exterior and the interior were 9.7 °C and the minimum temperatures of 8.1 °C, taking into account of the lack of external protection during periods when the temperature is quite low. Again, as in Scenario 1, in the same interval, a favorable scenario can be anticipated in the case of the correct use of the blinds.

The results collected from the relative humidity, in the heating station of Scenario 1 following the regulation EN 15251: 2007 [14] again, registered maximum values of 64.3 and 48.5%, thus verifying the compliance with the regulation and also the approximation of these data to category II whose range is between 25 and 60%. This verification of relative humidity is relevant because despite the season having increased rainfall and consequently the humidity of the air, in Mediterranean countries the behavior of the building does not compromise the comfort of people, in the quality of the air, as well as in the durability of the materials somewhat quite likely to happen.

In Scenario 2, it allows once again to verify the values obtained in relation to EN 15251: 2007 [14], which are not only in accordance with the category of the case study, III, but also with category II, referring to a level of normal expectation, recommended in the de-sign of new buildings and in rehabilitation. The values collected, maximum and mini-mum of 55.7 and 27.5%, respectively, with an average of 44.2%, due to the high temperatures recorded in the interior resulting from daytime sunlight, which, with open blinds, reduce humidity relative in space, even taking into account the maximum humidity registered outside 90.8%, (even if it doesn't rain) and minimum 30%. These interior values also allow us to anticipate that through the correct use of blinds and windows, in this season, the values will provide the best thermal comfort and conform to acoustic and luminous comfort.

Once again to understand the hygrothermal comfort of the apartments, the Operating Temperatures during the heating periods were evaluated, with Scenarios 1 and 2 indicated above. Within the comfort conditions defined by EN 16798: 2019 [18]. The graphs shown in Figures 8 and 9 were drawn from the operating temperature for an occupant sitting in the center of the compartment with winter clothes (1 clo). The indoor air speed was considered zero due to the fact that all windows are closed and the average radiant temperature is equal to the air temperature.



Temperature [˚C] Temperature [˚C]

Legend:
Maximum average temperature recorded
Category I Category II Category III
Minimum average temperature recorded
Category I Category II Category III
Results of the apartment with closed blinds

Inputs:
Air speed: 0 m/s
Metabolic Rate: 1 met
Clothing Level: 1 clo

Figure 7. Evaluation of the comfort in the apartment with the blinds closed (left) and open (right), from 05 to 12 January.

Through the interpretation of Figure 7 (left), the non-compliance with the regulation EN-16798 [18] is repaired in Scenario 1. This is due to the values of ambient temperature and radiant average being low and equal, because with closed shutters, there are no radiant asymmetries and air speed is zero. Something that only happens due to the inoccupancy in the building and the lack of sunlight in this scenario. Thus, the values collected are not within any comfort category of the standard, such as in the summer.

From the analysis of Figure 7 (right), related to Scenario 2, in the heating season, it is possible to verify that, when the operative temperatures are higher, there is compliance with the EN-16798 [18] standard, within category II, however, due to the lack of blinds, the operative temperature variation, recorded in Figure 11, is greater, with the average difference between the maximum and minimum operative temperatures, inside, being 8.3 °C, making it impossible to comply with the standard when these temperatures are lower. Even taking into account that the average difference between the extremes of the average operative temperature and the outside temperature are 11.2 and 8.8 °C maximum and minimum, respectively.

4. Conclusions

Despite the poor condition of the construction, abandoned and unused for decades, this research proved that, with cleaning and simple repair of the façade constructive elements, as well as the implementation of a regular maintenance, we can extend the life of the building and almost match current comfort standards. The proof of this are the results obtained by the "in situ" measurements. The operative temperatures are, however, those that, through data monitored, allow the building to be between categories I and II of the adaptive comfort model in cooling season, where the difference in indoor temperature peaks not exceeding 5 °C throughout the day, even with the window blinds always open. The operation of windows will certainly allow to even reduce more the thermal oscillation. During the heating season the oscillation was significantly higher, 11 ºC, complying to Category II during part of the day, but not complying during the night time. Closing the blinds during night time will certainly allow to significantly reduce the minimum temperature and the peaks difference, as the monitored value with blinds closed were under 2 ºC. In the refurbishment of buildings, "if there is no” strict application of principles, rules or standards that promote the rational use of energy, thermal comfort will tend to be achieved with greater use of mechanical heating and cooling systems, which will increase energy consumption in the sector, hence the pertinence of optimizing bioclimatic design. An environmentally conscious but also heritage respectful intervention should first look for the ability to respond to contemporary concerns and create the best conditions of comfort without mechanical supports or the introduction of new materials.

Acknowledgements

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