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Outdoor comfort analysis and microclimatic adaptation in a mid-20th century neighbourhood. A two scenarios simulation case study.

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Abstract

The Modern Movement extended its architectural and urban principles throughout mid-20th century Europe. Low-income housing developments were built with a novelty urban distribution, generating singular areas that are still widespread today in medium and large European cities. These neighbourhoods have suffered several modifications and updates that have changed their urban configuration. Furthermore, most of these housing complexes, which were built without thermal insulation, present social and economic difficulties. Today, with the overheating and the energetic global crisis, they face a serious fuel poverty situation. Authors have already researched passive cooling and how heat mitigation improves the free-running buildings indoor conditions. However, these widespread urban fabrics and how their modifications have improved or worsened their microclimate have not been adequately studied. This research proposes a microclimatic study through a simulation from two scenarios of the same case study, comparing the original urban status with the current one. For this purpose, the ENVI-met microclimate simulation software tool is used. As part of the proposed methodology, model calibration is supported by onsite data recollection. Thermal comfort is evaluated and confronted in both scenarios obtaining outdoor Physiological Equivalent Temperature (PET). Through the microclimate simulations it can be analysed that no relevant mitigation effect during the day were achieved by the interventions. Furthermore, on the current scenario a slightly night overheating effect compared with the original one was confirmed. Therefore, it can be concluded that this urban intervention through the years has been inefficient for microclimate comfort.

Keywords: Urban microclimate; Climatic simulations; Outdoor thermal comfort; Modern Movement urban fabric

1. Introduction

The worst emissions scenarios report of the Intergovernmental Panel on Climate Change (IPCC), project a near future in which the global average temperature could increase by up to 3-4 ˚C (IPCC, 2022). Although this increase would be worldwide, cities will be the most affected areas according to (Saeed Khan et al., 2022). The last UN global population expectations (UN, 2022), predict that by 2050, 68% of people will live in cities, this becomes a crucial issue. In fact, the situation in cities is feeding back on itself, the largest population and human activity, the largest density, and the most natural environmental transformations. Besides, cities overheating and as a consequence, the worsening of outdoor comfort conditions is directly related to the physical behaviour of the construction materials used in the cities (Shooshtarian et al., 2018).

To face this problem, architects and urban planners must take into account how their designs can improve or worsen the city microclimate (Sharmin et al., 2017), which involves a previous study of the microclimate of cities and its improvement. In this sense, one of the most widespread type of European urban fabrics, that has not been properly researched in its microclimate aspect, is mid-20th century Modern Movement (MoMo) developments. These usually low-income neighbourhoods were spread across all industrial cities as result of the after-war housing effort. Architects designed the new urban fabric according to the principles of the MoMo values that were extended in Europe. This results in the presence of many urban areas with common design principles that are being used today. Even if these developments introduced some healthy and climatic considerations, in the light of climate change perspective it has to be stated they were designed to face more temperate temperatures. These buildings have a poor thermal-energy standard compared with current ones, while both dwellings and urban areas have been severely modified since their erection. Most of these dwellings were erected (and still are performing) as free-running units without HVAC equipment. Moreover, according to (Halkos & Gkampoura, 2021), there is an important percentage of population living in these old developments facing a fuel poverty situation. HVAC equipment.

Most of these urban areas were designed with large open green spaces that have been transformed into large concrete areas and asphalt surfaces. Considering that urban materials and geometry have a direct implication in microclimate conditions, so does outdoor thermal comfort. Moreover, in free-running buildings, outdoor climate has a direct impact on the building's thermal conditions, affecting the comfort conditions and inhabitants' health. The study of this urban fabric specific microclimate and how these spread typologies perform today with current climate is a relevant research gap that must be considered.

This article focusses on the microclimate of a case study of a mid-20th century urban area, analysing the outdoor conditions of the neighbourhood, comparing the performance of the original development versus the refurbished one, after several urban modifications. To this purpose, both microclimate simulations are run with ENVI-met tools, obtaining and confronting the PET outdoor comfort index in both scenarios.

2. State of the art

Passive urban cooling techniques have been previously investigated as an effective way to mitigate urban overheating (UO) (Santamouris et al., 2020). Some authors have proven that UO is directly related to albedo and other properties of urban surface materials as (Lopez-Cabeza et al., 2022) proved in semi-outdoor (Roa-Fernández et al., 2022)spaces. However, other studies have also exposed that microclimate conditions have a strong link with urban fabric configuration. Geometry has been shown as one of the most influential factors by (Johansson, 2006), which means that the urban typology is strongly related to the microclimatic performance of the area. In this sense, some researchers (Maiullari et al., 2021) have shown how open spaces improve heat mitigation in dense urban fabrics, applied to Venetian old city centre. Others have studied how urban political decisions could affect the microclimate (Heris et al., 2020), as a consequence of urban planning regulations. , so it is a research gap.

As all these factors will affect local microclimate, they will also affect outdoor human thermal comfort as extensively addressed by (Nikolopoulou et al., 2001). Regarding thermal comfort, one of the most spread adaptative indices is the PET, developed by (Höppe, 1999a). This index reflects the physiological response of people adapted to outdoor environments.

In order to study the urban microclimate, some authors (Mauree et al., 2019), have proved that computational simulation tools combined with onsite monitoring are the most effective to achieve good knowledge. On-site data provide objective information and are used for the model calibration, while the simulation tools can obtain results for various scenarios, even if they were real or not. Within all microclimate simulation strategies, computational fluid dynamic (CFD) tools are the most validated due to the accuracy of their results. Among these software tools, ENVI-met is one of the most used and accepted by the scientific community (Acero & Arrizabalaga, 2018) . ENVI-met tools are a three-dimensional microclimate pack designed to simulate surface-plant-air interactions in an urban environment with a resolution of 0.5-10 metres. It was programmed by (Bruse & Simon, 2004), and provides results of the microclimate simulation of outdoor environments, obtaining the main climatic parameters. The air and surfaces parameters can be measured in the three-dimensional grid along the model. These results are used to calculate the thermal comfort indexes, which provide information about pedestrian thermal perception. Research information about pedestrian thermal perception.

In following sections, the case study area and its evolution are explained, as well as the methodology followed for the microclimatic simulation and comparation. A stepped guideline based in literature is provided and main technical aspect and ENVI-met setting are described. Finally, main results are shown, discussed and the conclusion raised.

3. Materials and Methods

3.1. Materials: Case study

Figure 1: Location of the neighbourhood of the case study.

This research analyses the microclimate of a neighbourhood of the mid-20th century in the Spanish city of Valencia. It was influenced by the principles of the MoMo in its design but also suffered important transformation through its history. Valencia is one of the largest cities on Spain, it is in the eastern side of the country, on the Mediterranean coast (Figure 1). It has a latitude of 39.46 ° and an altitude of 4 metre above the level of the sea. The Valencian climate is highly influenced by the Mediterranean Sea; in fact, the case study area is only one kilometre from the sea. Its climate has been assigned as *BSh*, according to the most recent Köppen classification (Chazarra Bernabé et al., 2022).

Figure 2: Original aspect of the development just built in 1963. (García-Ordóñez & Dexeus Beatty, 1963), open access.

Figure 3: Current aspect of the area in 2022, provided by Google Earth.

The case study, the *Virgen del Carmen* Group, a low-income development built in 1962. It provided new houses for victims of a river flood. At that time, Franco's regime was promoting the construction of numerous dwellings, due to the lack of homes after the war. Immerse in that dynamic, the constructive system needed to change. Standardising, prefabrication, and velocity were a must. Moreover, at that moment, the MoMo' values were coming to Spain (Roa-Fernández et al., 2022).

In that context, the case study development was planned as a new isolated neighbourhood in the suburbs, like elsewhere throughout Europe. New urban, constructive, and design concepts were implemented for the construction. The neighbourhood was organized in two big parts that contained several isolated buildings each. There was a large open space of sandy terrain crossed by thin pedestrian walkways. Two diverse types of blocks of flats were planned, lineal and tower buildings, combining different heights. Only two roads crossed the development; almost all traffic was displaced to the outer ring. Scarce vegetation was planted, so the public space consisted of a vast empty surface with no canopy between the separated buildings. The final urban image was still a novel urban style in Spain (Figure 2 and Figure 4).

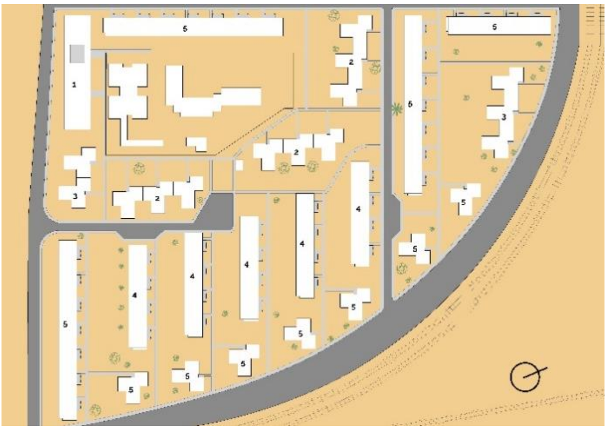

Figure 4: Urban plan of the original status of the development.

Figure 5: Urban plan of the current development status.

Although this case study is a specific development, this urban typology is an archetype of that time urbanism, when the MoMo principles were spread in Europe and numerous new developments were being built in the mid-20th years. This converts the case study into an applicable research with interesting and transposable results.

As happened in other similar neighbourhoods, the development of Virgen del Carmen has suffered important alterations that have severely modified the configuration, materials, and image (Roa-Fernández et al., 2022). In fact, this research study revealed how all these changes could affect microclimate performance. Since it was inaugurated, the area has been modified by successive projects promoted by the Administrations. As a result, today the urban group seems more like a traditional urban fabric. The original big areas have been divided into small ones, which now contain one, two, or three buildings each. New asphalt roads and car parking areas have been constructed between the new blocks, changing the old sandy terrain for new large heavy and dark surfaces. Additionally, new concrete tiles have been introduced. Furthermore, an ambitious garden project has been implemented that introduces many new trees that provide a considerable green canopy (Figure 3 and Figure 5).

3.2. Methodology

3.2.1. *Geometrical and materials survey*

As a first step, we started collecting historical and technical documentation of the case study original construction project. This information was confronted with cadastral cartography and completed with onsite data collection. The objective was to obtain a complete geometrical survey with information about the measures, materials, colours, vegetation, etc. Once we had obtained all the available information, we characterized the urban description of both scenarios: the original status, just after the construction, and the current one.

3.2.2. *Climatic data collection*

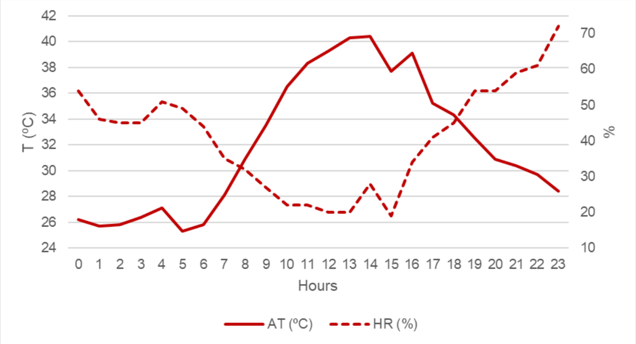

Figure 6: Official AEMET data of the simulation day. Temperature in continuous and relative humidity in discontinuous.

The simulation is performed in summer 2022, the hottest since there are registers according to the Spanish National Meteorological Agency (AEMET). The official meteorological data were complemented with onsite climatic data that provided more exacted and located data and allowed us to calibrate the simulation. Considering AEMET's records, we decided to simulate August 14th, which was one of the warmest days of the whole summer. These data were collected by an official meteorological station, located at the airport, 12 kilometres in the west of the case study area. The hourly air temperature (AT) and relative humidity (RH) were collected during the simulation day, and they are shown in Figure 6. Local climate data were also collected onsite during a climate walk and were used to calibrate the model. Two multifunctional measuring devices were used: Trotek TC100 was used to collect the AT, RH and glove temperature. On the other hand, PCE-SPM 1, a radiation meter, was used to measure global radiation. The technical data provided by the manufacturers are shown in Table 1.

Table 1: Devices technical parameters.

Thermohydrometric: Trotec TC100

Magnitude	Unit	Range	Resolution	Accuracy
Air Temp.	°C	0-50	0.1	± 0.6
Relative Hum.	%	0-99.9	0.1	± 3/5
Dry-bulb Temp.	°C	0-80	0.1	± 0.6

Radiation meter: PCE-SPM 1

Magnitude	Unit	Range	Resolution	Accuracy
Radiation	W/m2	0-2000	0.1	± 10

3.2.3. *Geometrical and material's properties configuration*

The initial data served to configure two simulation models in ENVI-met. Version 5.0 was used in this investigation. First of all, the geometry survey was drawn in a 3D-CAD software. Volumes, urban surfaces, and trees' position were model for both scenarios: the original status (Figure 7) and the current one (Figure 8). Then, SketchUp software was employed, through its ENVI-met plugin to configurate the geometry and transform it in an ENVI-met model. This plugin recognises the geometrical model and transforms it into ENVI-met entities by assigning properties previously recollected (Table 2). Trees were assigned as ENVI-met entities, combining several species existing in the neighbourhood.

Figure 7: Original-state scenario ENVI-met model. (Colours are an identification layer).

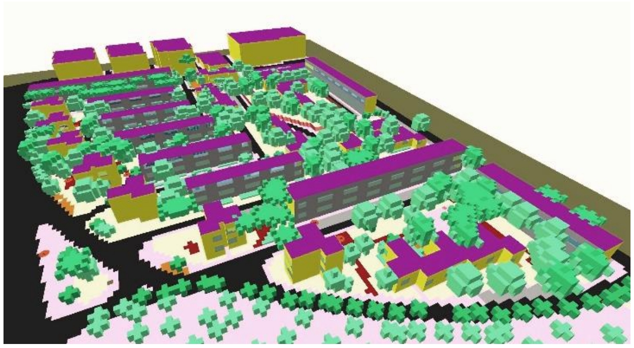

Figure 8: ENVI-met model of current state scenario ENVI-met model. (Colours are just an identification layer).

Table 2: Properties of materials assigned as ENVI-met entities.

WALLS				
Scenario	Original	Common		Current
Material/ properties	Yellow brick wall	Concrete panel	Glass	Yellow mortar
Absorption	0.49	0.7	0.05	0.51
Transmission	0	0	0.9	0
Albedo	0.51	0.3	0.05	0.49
Emissivity	0.75	0.85	0.93	0.87
Spec. Heat (J/(kg·K))	1000	1000	750	1000
T.Conduct. (W/(m·K)	0.667	1.32	1.4	0.4
Density (kg/m3)	1140	2000	2200	875

ROOFS		
Scenario	Original	Current
Material/ properties	Red ceramic tile	Red painted ceramic tile
Absorption	0.74	0.69
Transmission	0	0
Albedo	0.26	0.31
Emissivity	0.9	0.96
Spec. Heat ((J/(kg·K))	800	800
T.Conduct. (W/(m·K)	1	1
Density (kg/m^3)	2000	2000

SOILS				
Scenario	Original	Common		
Material/ properties	Ceramic tiles	Sandy Soil	Clay Soil	Asphalt
Albedo	0.38	0.29	0.17	0.2
Emissivity	0.95	0.9	0.91	0.93
Z^0 Roughness Length (m)	0.01	0.05	0.015	0.01
Scenario	Current			
Material/ properties	Parking concrete	Red cobblestone		Pedestrian pavement
Albedo	0.4	0.41		0.45
Emissivity	0.93	0.63		0.93
Z^0 Roughness Length (m)	0.01	0.01		0.01

3.2.4. Configuration of the ENVI-met model.

Once the geometry, materials, and properties have been fully exported to the settings of the simulation software, the climatic environment and location must be completed. In this case, these inputs are the same for both simulations, as they are performed on the same day, 14 August, and the same situation. Location data, model size, and grid set are shown in Table 3. The simulations were run for 25 hours, from 4 am to 5 am on the next day. By this way, the software has enough time to adjust internal calculations in order to provide good diurnal results, and we have a complete day circle to analyse (Salata et al., 2016).

Climatic data from AEMET were introduced using the simple forcing mode method. Other settings were assigned as follows:

- Humidity at 2500 m: was calculated following (Salata et al., 2016).
- Wind speed and direction were established according to the average of the AEMet day data.
- The length of the roughness was established according to the typology of urban areas (Stull, 1988).
- Cloud cover: it was 0, as it was a totally clear day.
- The initial building temperature was estimated knowing that most of the buildings work in a free-running system.
- Temperature constant: no (free running).
- Plant settings and calendar: by default.
- Timing section: By default.
- Soil conditions: They were set according to (Salata et al., 2016).
- Radiation settings: all by default except the solar adjustment factor, which was adjusted following the official AEMET data.

All the specific values assigned for the settings are shown in Table 4.

Table 3: Simulation model space values.

Field to be compiled	Values and data
Name of location	Valencia, Spain
Latitude	39.47
Longitude	-0.38
Size of grid: dx / dy / dz	2 / 2 / 3
Model dimensions: x /y /z	214 / 252 / 20
Telescoping factor	0%
Rotation out of grid north	18º
Level above the sea	4 m
Nr of nesting grid	5

Table 4: General settings assigned in *simple forcing* mode, ENVI-met.

Field to be compiled	Values and data
Start date	2022/08/14
Start time	4 a.m.
Simulation time	25 h
Humidity in 2500 m	4.5 g/kg
Windspeed (average)	3.53 m/s
Wind direction (average)	17.80º
Roughness Length	0.10
Clouds (all)	0
Building initial Tº / Keep constant	27.0 ºC / No
Soil humidity	ENVI-met default
Soil temperature at: 0-20 / 20-50 / 50-200 / <200 cm	20.0/ 19.0/ 17.0/ 15.0 ºC
Solar Adjustment Factor	0.91

3.2.5. *Calibration*

Once the model setting was completed, to get the most accuracy from the simulation, the current state model was calibrated. For this purpose, the onsite climatic data are used as constatation. The simulation was run at the same time that onsite data were collected. Then, the in-situ AT and the ENVI-met AT results were compared and confronted. After several adjustments in the grid size, the final configuration of the model was set, and the calibration errors were calculated. These errors provide information about how much the simulation results are similar to the on-site one. To evaluate the error, previous work (López-Cabeza et al., 2018) was used as a reference. Also, according to the research of (Willmott, 1982), the determination coefficient r2 is not the most appropriate error to take into account in these kinds of confrontations. Finally, the errors obtained show a very high level of accuracy of the model (Table 5).

Table 5: Calculated errors for the model calibration.

Errors	Perfect values	Obtained value
Root Mean Square Error (RMSE)	0	0.36
Systematic RMSE (RMSEs)	0	0.20
Unsystematic RMSE(RMSEu)	0	0.49
Mean Absolute Percentage Error (MAPE)	0 %	0.8 %

3.2.6. *Comfort indexes obtaining*

Finally, calibration adjustments were applied to both scenario models, and both simulations were run. Once ENVI-met had obtained the final climatic result, the comfort index. PET was calculated for pedestrian perception. It was established considering the conditions at 1.5 m height, a medium-aged average man with summer clothes (0.5 clo). PET values were compared in both scenarios, analysing two moments of August at 14 pm and 22 p.m. This way, the impact of urban intervention on human comfort was evaluated at the warmest moment of the day according to AEMET data and at the beginning of the night after all the sun radiation. As a consequence, the microclimate of a MoMo urban development was analysed specifically performing in hot weather.

4. Results and Discussion

Equivalent temperatures of PET at 1.5 m height are shown in the followings heat map. The results are divided: 14 p.m. PET temperatures are shown in Figure 9, while results from 22 p.m. are shown in Figure 10.

First, if we look at the 14:00 p.m. heatmap (Figure 9), most relevant results are the extremely high equivalent temperatures that are reached. Within both scenarios, the minimum obtained is 46.5 ° C (PET), which is classified as very hot on the PET scale (Höppe, 1999b). In the first scenario, almost all the area is between 54-55ºC, just the shadowed areas (provided by the buildings and the scarce vegetation) get lower values from 49ºC to 54ºC. As originally the area was a free open space, with almost no interruptions, the thermal sensation is very homogeneous. There is a remarkable heat concentration in between the buildings, mostly in their South facades. Due to the radiation reflected by constructions, a slight increase of approximately 2-4 ° C is reached in these areas. On the other hand, attending to the current scenario (Figure 9), with the nowadays urban configuration, a slight improvement in temperatures can be observed. Due to the shadows of the new green canopy, direct solar radiation is blocked, and the temperatures are slightly reduced just in the localised areas under the canopy of trees. However, the most common thermal perception is still around 54-550C; only the most covered areas have an effective temperature reduction of about 5 ° C. Nonetheless, the minimum temperatures reached are still listed as very hot on the PET scale.

Secondly, we examine the 22:00 pm PET results (Figure 10), comparing the original scenario versus the current one. Observing the results of the original scenario, PET temperatures are cooler, between 27-29.5 ° C, which are catalogued as slightly warm on the PET scale. Thermal perception has improved greatly in the early night hours, with no solar radiation, and temperatures are very close to the values considered as thermal comfort. The enclosed areas between the buildings are the warmest, due to diffuse radiation irradiated by the facades and the ventilation difficulties. However, according to the PET results of the current scenario, there has been a general increase in temperatures. This slight increase mostly affected the inner part of the neighbourhood and the space between buildings. This zones, as a consequence of the urban transformation, are covered now with concrete and asphalt surfaces, but also many vegetation areas. The new heavy urban surfaces radiate infrared energy back during the night and the vegetation make it difficult the ventilation, so it is more complicated to mitigate the heat by the night fresh air. This is translated into small heat bags with an increase up to 2 ° C with respect to the original scenarios. Therefore, the current configuration is producing a slight deterioration in night-time thermal perception.

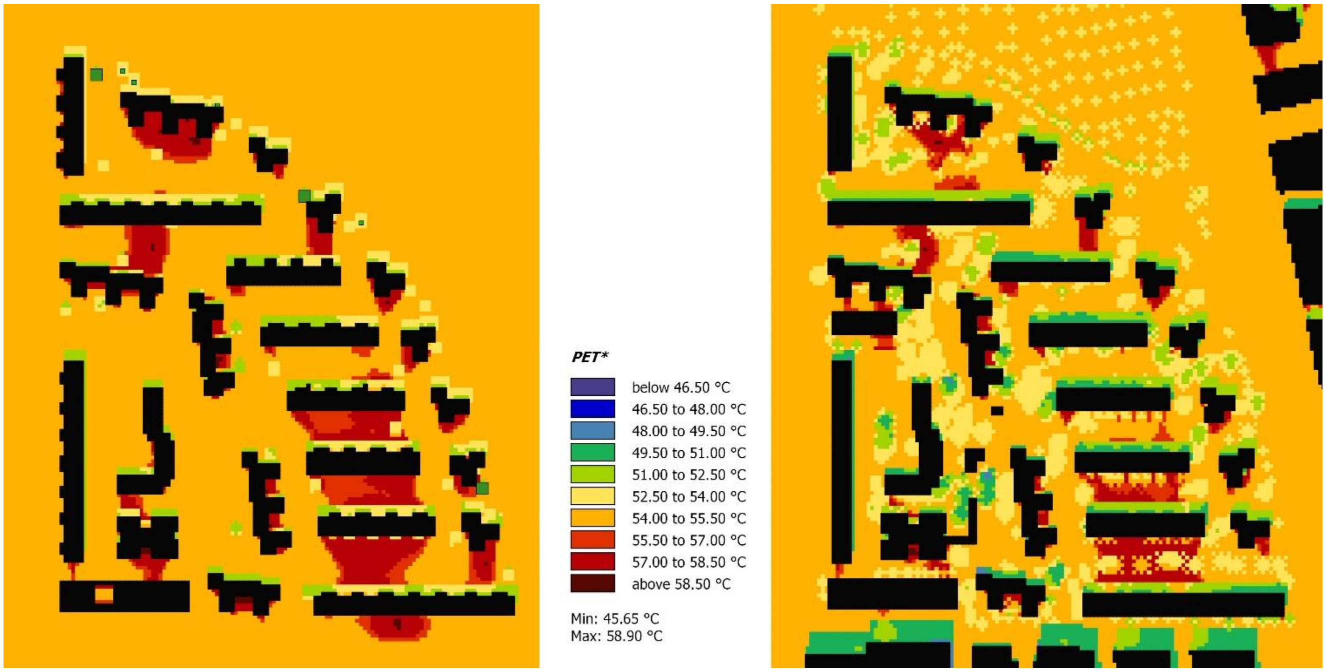

Figure 9. PET equivalent temperatures obtained at 14 pm on 14 August 2022, for the original urban scenario (left) and the current one (right).

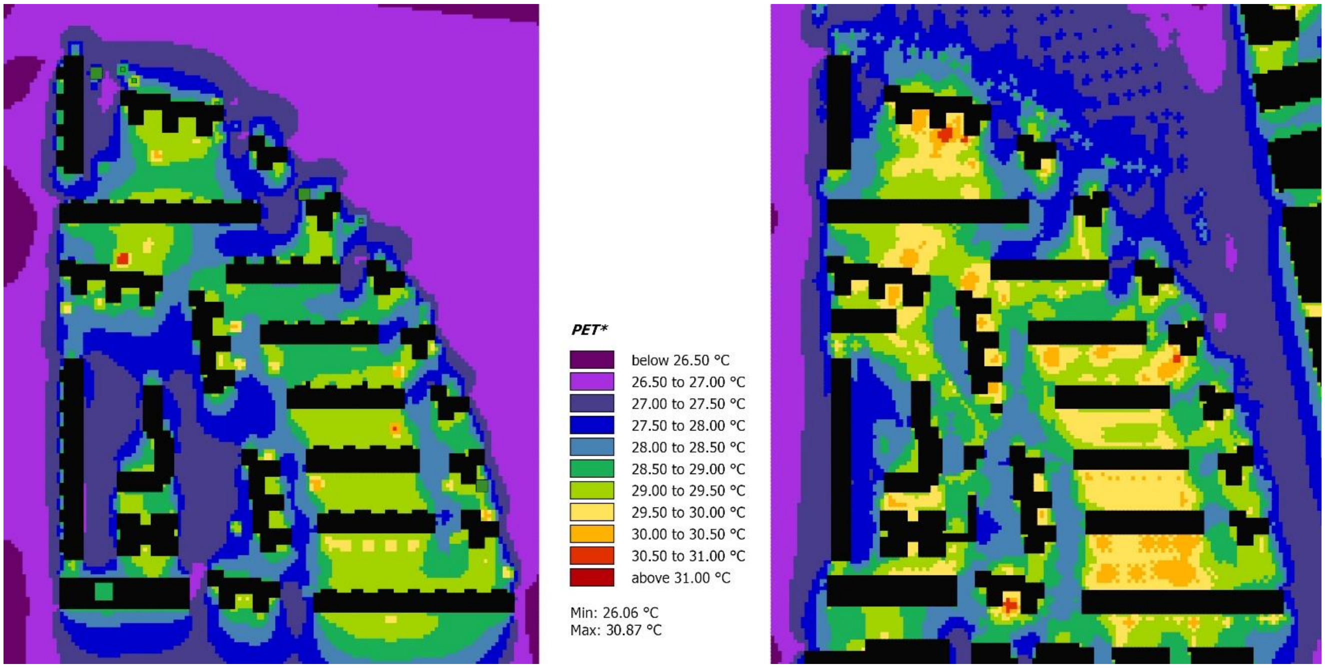

Figure 10. PET equivalent temperatures obtained at 22 pm on 14 August 2022, for the original urban scenario (left) and the current one (right).

5. Conclusions

The microclimate performance of a mid-20th century neighbourhood has been evaluated through the confrontation of two scenarios, its original urban status, and the current one after several urban modifications. This research shows the methodology followed to study the results of thermal comfort in an area that is an archetypal of the urban development of the European MoMo. Outdoor human thermal comfort has been obtained by confronting the ENVI-met two scenarios in the microclimatic simulation tool, obtaining PET temperatures for two moments in one of the warmest days of the summer of 2022.

The results show that the area reaches very hot equivalent temperatures in general during the day, far from thermal comfort. When attending the first confrontation in the central part of the day, the urban transformations of the current scenario receive a slight heat mitigation compared with the original. Although the new large green canopy blocked direct solar radiation, the effect is very light and localised. However, examining the first hours of the nigh time, the results show that the current scenario worsens the thermal comfort compared to the original one. The big transformation carried out in the urban surfaces, adding heavy and dense material, with low albedo, results in a day-time absorption of heat, that is difficulty released during night. Furthermore, trees that were beneficious during the day, at night increase relative humidity and difficult night ventilation, which hinders heat mitigation worsening the thermal sensation.

In conclusion, although the urban transformation suffered by the neighbourhood has some beneficial effects during the day due to vegetation, they are very limited. However, their effect during the evening and the night-time is unfavourable for the thermal comfort due to the new materials used for the surfaces. Finally, this research concludes that after the deep urban transformation suffered, this MoMo development has almost not improved its comfort during the day and has worsened during night, so the urban intervention has not been appropriated from a microclimate and comfort perspective.

This research provides a useful demonstration of a methodology that could be use by stakeholders to evaluate the urban microclimate in two ways. On one hand, to identify specially affected existing areas where the intervention is needed. And on the other hand, the urban improvement designed actions can be evaluated in the very early design stages.

It is important to acknowledge certain limitations of this work. Firstly, the selection of our study case focuses on a specific geographical location and time period, which may restrict the generalization of our conclusions to other regions or seasons that could be further studied and compared. Although we conducted several measurements and calibrations, future research could benefit from using locally monitored weather conditions to assess the Urban Heat Island (UHI) effects. Furthermore, this research focused on the comparison of results based on the impact on the PET thermal comfort index. Due to the limitations in the paper length, a more in-depth analysis of internal parameters affecting human thermal comfort was not possible. Future studies could delve deeper into these parameters and explore differences among various comfort indexes.

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