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Sun-Shading Sails in Courtyards: An Italian Case Study with RayMan

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Abstract: Forecasts of a drastic increase in temperatures in the coming decades are driving the adoption of design strategies and solutions to improve the livability of urban environments. Increasing attention is being paid to the thermal comfort of open spaces by both designers and researchers. Nature-based solutions and man-made devices to improve the comfort of outdoor spaces during summer are spreading, but effective, easy simulation and design support tools for this purpose are still lacking, as most of the available software such as ENVI-met or RayMan cannot model such devices. As Physiological Equivalent Temperature (PET) is one of the most relevant and comprehensive indicators of Outdoor Thermal Comfort (OTC), this study aims to investigate PET variations of different artificial shading systems and propose a simplified methodology for assessing them through analytical simulations with RayMan software. When modeling the shading elements, the trick adopted for this purpose is to associate different cloud densities with the shading provided by the screens, thus overcoming a gap that affects the software. The procedure is digitally tested in a covered courtyard case study in Bologna (Italy). Diverse options proposed by the designers for textile screening materials have been compared, showing that these reduce by at least 1 °C the PET-gauged thermal stress. Beyond specific results, the main outcome of this study is the procedure developed to simulate sun-shading sail effects on OTC by means of RayMan, which can support designers in planning effective solutions for open space livability in summertime.

Keywords: heat stress; PET; RayMan; courtyard; sun-shading sail

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1. Introduction

Due to climate change effects, scientists forecast an increase in global temperature of at least +1.5 °C by 2050 in the lowest emission scenario [1]. In Europe (EU), this will result in at least a +1.6 °C Annual Mean Temperature and +1.9 °C Max Temperature of the warmest month in 2050, with respect to the reference period 1985–2014 [2]. Under all future climate change scenarios for EU, the number of hot days, as well as the intensity (i.e., duration +63%) and frequency of heatwaves (+19%), are expected to increase. Consequently, rising mean temperatures will intensify heat stress in cities, particularly in the Mediterranean region and Eastern Europe. Outdoor thermal comfort in urban environments will be increasingly affected with significant implications on livability in cities and citizens' wellbeing [3]. Therefore, the protection of urban areas from global warming will be one of the key challenges of the next decades that policy makers and designers should address as soon and effectively as possible [4,5].

In this regard, a consistent and growing body of literature is focusing on the evaluation of Outdoor Thermal Comfort (OTC) in diverse outdoor spaces, from public pathways and squares [6–9], to parks [10] and building courtyards [11–15]. These are all, in fact, collective or public spaces intended for relations among citizens, where good OTC levels are essential to encourage or even allow people to use outdoor facilities [16].

Many authors are thence addressing the OTC of open spaces within the built environment [17], either discussing assessment methods and tools [16,18,19] or suggesting guidelines for improvement [20,21]. To this end, several strategies and design solutions to mitigate or adapt to the effects of climate change in cities are emerging. Among those specifically aimed at coping with heatwaves and hygro-thermal discomfort in cities are cool roofs; cool pavements and road surfaces; green roofs and walls; nature-based solutions (trees and urban vegetation; cooling water-based methods); and alternative shading devices [22–24].

Accordingly, several tools and software have spread to assess the level of OTC in open spaces both before and after design, especially focusing on those areas where people are expected to stay longer, such as squares and building courtyards. Among the most used tools for this purpose there are RayMan, ENVI-met, Project Vasari, IES.VE, TRNSYS, and NicheMap [25–29].

1.1. Evaluation of Thermal Comfort in Courtyards

Thermal comfort in courtyards has been extensively addressed in the literature, either by field monitoring, analytic simulations, or their combination, as reviewed by [30].

Many researchers have tried to investigate the shading effect due to courtyards' shape, orientation, and boundary surfaces (e.g., building walls) in improving OTC. Safarzadeh and Bahadori have evaluated the shade effects of building walls and trees on courtyards in Teheran, finding that these features alone are not enough to ensure adequate OTC during peak heat hours [15]. Some scholars have tried to identify which are the best shape and orientation of courtyards to improve the OTC in hot climates, through the mutual shading of the walls such as in the hot-arid Iran [31] or hot-humid Malaysia [32,33]. Martinelli and Matzarakis performed a systematic analysis of courtyard typologies in six Italian cities from North to South and found that a higher height/width ratio has a stabilizing effect on OTC in both summer and winter [14]. Forouzandeh reports several studies demonstrating that vegetation, constructions materials, as well as the land treatment and use also influence OTC, in addition to the courtyard geometry and orientation [34,35].

The literature on the subject reveals that ENVI-met is one of the most widely used software for forecasting microclimatic conditions in courtyards, as it returns through maps both data on air, soil and building surfaces, as well as the thermal comfort expressed through the Physiological Equivalent Temperature Index (PET), the Universal Thermal Climatic Index (UTCI), and the Predicted Mean Vote (PVM) with relation to OTC [36].

ENVI-met enables the modeling of the environment to be simulated by means of an orthogonal Arakawa C-grid, which allows obtaining useful maps for each variable as an output of the process [36–38]. However, when testing the software to measure courtyard microclimate, some authors point out its inaccuracy if specific values for single points or narrow areas are required. Forouzandeh highlights significant errors in the estimation of large sunny areas too [34]. Furthermore, López-Cabeza et al. argue that there is a significant deviation from the simulated to the experimental data recorded on site, implying that the ENVI-met outputs are not accurate enough to estimate the OTC in nZEB buildings, where even minor variations are relevant [13]. Nevertheless, the software is generally credited with having acceptable accuracy in simulating the microclimate in medium-sized courtyards.

Having made a comparison among three different tools (CMRT, ENVI-met, and Ladybug) used to simulate the OTC of a Chinese courtyard [39], Wu et al. argue that the first is faster and more reliable in calculating the mean radiant temperature of surfaces, but no other features are compared.

Beyond possible flaws in the software, all these studies refer to applications on uncovered open spaces. Very few studies address instead the effect of covered courtyards on OTC levels, although these are increasingly adopted in the design practice as climate change mitigation devices. Shading is indeed one of the most effective strategies to improve OTC in courtyards [11], either due to shadows cast by walls on narrow–medium sized open spaces, or that provided by artificial covers of the larger ones (e.g., sun-sail shading).

1.2. Covered Open Spaces and Courtyards in the Literature

Technical solutions to screen squares, urban pathways, and courtyards with textiles providing shading are indeed rapidly diffusing in the design practice. Their expected direct effects are the reduction in solar irradiance and thus the temperature of urban surfaces. Vernacular architecture provides several examples to this end, among which veils used in Seville (Spain) to shade urban streets during summer (known as *toldos*) are one of the most famous. However, although the benefits of these solutions on OTC are foreseeable, there is a paucity of literature about quantifying the effects of textiles screens on urban open surfaces [36], and especially regarding courtyards.

Garcia-Nevado et al. investigate the cooling potential of textiles (specifically sun-shading sails) on urban surfaces [36]. By means of on-site measurements taken in a number of streets in Cordoba (Spain), they show that sun sails can effectively mitigate heat while requiring low levels of intervention. Similarly do Elnabawi and Hamza for Egypt, correlating on-site field measurements with the results of a structured questionnaire on thermal sensation votes [16]. The same has been observed by Cantini et al., who compared the shading of open spaces provided by different lightweight structures through on-site measurements using sensors, the solar absorption coefficient of the material, the solar transmissivity coefficient, and the reflection of solar radiation [38]. Similarly, Medina et al. tried to analytically evaluate the effect of textile cover of the Expo amphitheater of Seville, still based on input derived from on-site sensors [40]. Meanwhile, Lee et al. have measured the effect on the OTC of transparent ETFE cushions screening a courtyard in Central Europe [41]. The shading effect of adaptive artificial trees on urban surfaces was also evaluated by Rocio et al., who performed both in situ measurements and ENVI-met computational fluid dynamics simulations but fail to mention what material the observed shade screens are composed of [38].

What emerges from this literature is that most of the available studies are based on on-site measurement or tools that do not allow the modeling of textile materials, while a simple tool capable of simulating the effects of different artificial shading types on open spaces will be highly valuable to support designers in the early stages. Indeed, a simple procedure or tool that is user-friendly and does not require a long calculation time would allow designers to understand the effects of diverse solutions on OTC, in order to consider them as viable options to submit to further validation with more precise simulation tools.

This represents a major research gap that deserves further investigation and studies to help the real-world improvement of OTC in open spaces. Technical solutions such as canopies and covered courtyards still lack an analytical basis of prediction and calculation which could instead guide the design towards the best shading solution, including considerations on the covers' shape and the properties of the materials used. Unlike what happens for open courtyards, here, ENVI-met cannot be used for simulation as it does not allow the modeling of textile shading screens but only of "rigid panels", such as those used in the study by Elgheznawy and Eltarabily [42].

2. Research Goals

Trying to fill the lack in design-support tools for simulating the features of screened courtyards, this paper investigates variations in thermal comfort due to different artificial shading options (e.g., sun shading sail) and suggests some tricks to assess their effect through numerical simulations provided by computational software. The overarching scope is to offer an easier to understand and limited time-consuming methodology to draw designers closer to this issue and allow them to handle it during the early stages of the process. A simplified approach to OTC scenarios comparison is thus proposed, whose ease of implementation can justify the lower accuracy of results compared to more sophisticated approaches, as other authors did in similar fields [43,44] and beyond.

In our research, we define a "sun shading sail" as a layer composed of synthetic membrane, or composite, or textile material, which is used to cover an open space and to screen it from direct solar radiation with the goal of shadowing the space below. This definition partially matches that provided for "tarp" by the *Oxford English Dictionary*, which however stresses on the waterproof features of the layer as "a sheet used to cover things with and to keep rain off" that is not relevant to the study (Figure 1). The specific goal of this article is to understand the potentialities and evaluate the computation methods of the software suitable for simulating the effects of shading screens deployed over courtyards or other unbuilt urban spaces, in terms of PET variations they can contribute to attain.

Figure 1. Example of sun-shading sails to cover part of a courtyard (Credits: G. Mengucci and G. Abbrucciati).

In fact, the commonly adopted software for assessing thermal comfort in those spaces do not allow modeling tarp or floppy material layers acting as screens. For example, the numerical discretization scheme used by ENVI-met does not allow the effect of a tarp to be simulated if not considering it as a solid ceiling.

On this premise and aiming at developing and testing a method to fill that gap, we opted for RayMan and associated different cloudy sky indexes to various screening options, according to the transparency of the sail material, as described in the following paragraphs. Looking beyond these first results, we aimed to stimulate further research and advancements into the software for modeling this type of shading systems.

A main assumption of this study is to focus on PET as a crucial indicator of OTC. This is indeed defined by Hoppe [45] as the physiological equivalent temperature at any given place (outdoors or indoors) and is equivalent to the air temperature at which, in a typical indoor setting, the heat balance of the human body (work metabolism 80 W of light activity, added to basic metabolism; heat resistance of clothing 0.9 clo) is maintained with core and skin temperatures equal to those under the conditions being assessed. In brief, six variables which characterize the outdoor open space affect the energy balance equation expressed by the PET index. Two main variables are related with the human body, namely 1. metabolism, measured in met, and 2. clothes, measured in clo. Four additional variables are related with the outdoor environment: 3. air temperature, and 4. mean radiant temperature affected by sun, sky, and floor; 5. relative humidity induced by evapotranspiration, and 6. air velocity. As for these latest, we decided to focus on mean radiant temperature (Tmr) by acting on the sky and sun features (shading and cloudiness) as concurrent affecting factors.

3. Methodology

The methodology, which is supposed to be replicable in other case studies, adopted the following steps:

1. Modeling the context and case study's physical features [46,47], implementing the geometry of the courtyard into the RayMan software.
2. Defining the courtyard floor surface temperature, considering 37 °C and 39 °C as two cases useful in assessing the relevance of this variable. These 2 floor surface temperatures were selected as being representative of common flooring materials in sunny days, respectively, of grass or pavement with a medium reflectance surface (average 37 °C) and asphalt or other similar pavements with low reflectance (average 39 °C). Further details and reasoning behind this can be found in previous studies such as [48,49].
3. Defining alternative scenarios by associating the shade/cover material features and RayMan cloudy indexes.
4. Generating the output to verify correlations between cloudy coverage levels, mean radiant temperature, and PET, as observed on the hottest day of the previous year [45,50].

A possible next step (n. 5) should be a comparison of simulated data with on-site measurements. Even though, at present, the sun-shading sail of the case study has not been realized, the methodology aims at evaluating possible variations of PET and Tmrt due to diverse shading materials through the cloudy index correlation in RayMan. Therefore, on-site measurement is a further step to verify the accuracy level of the simulation. However, it does not prevent this procedure from being proven as effective.

Following the methodology that has been devised, Figure 2 shows the flowchart of the procedure that a potential design team or consultant can implement, while Figure 3 describes graphically the cloudy sky trick. It is assumed that the designer/design team is responsible for the selection of a set of sun-sail shading materials to be simulated, and that a final decision about the best material can take advantage of the results from this procedure, albeit not being limited to these.

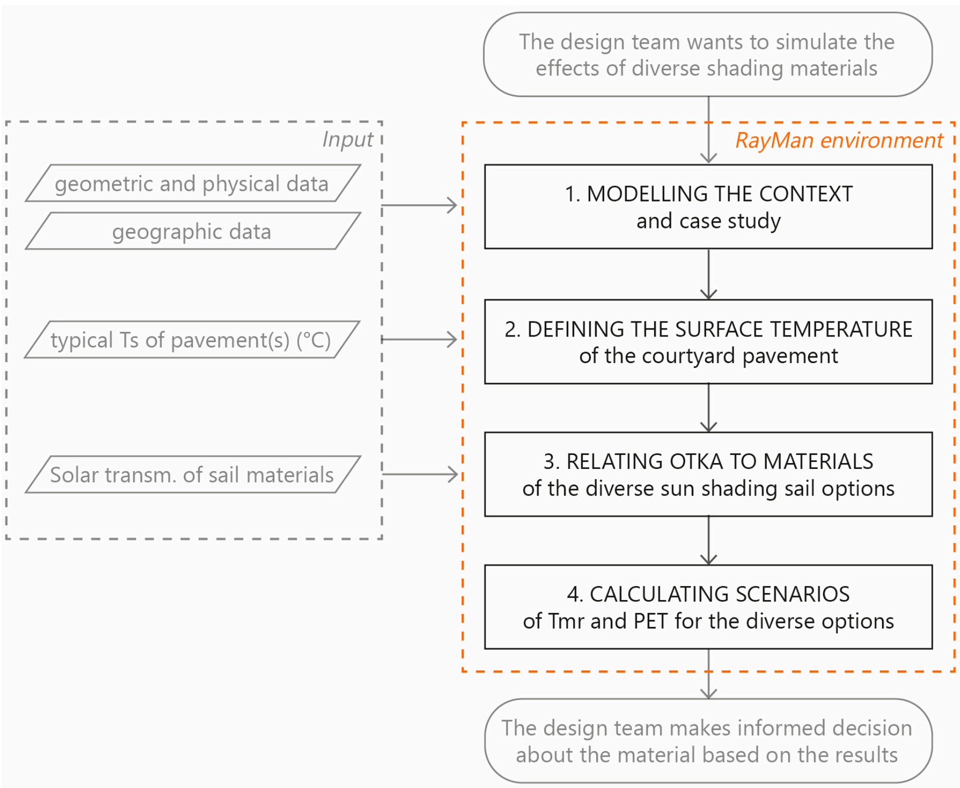


Figure 2. Simplified procedure applied to simulate the effect of sun sails on OTC.

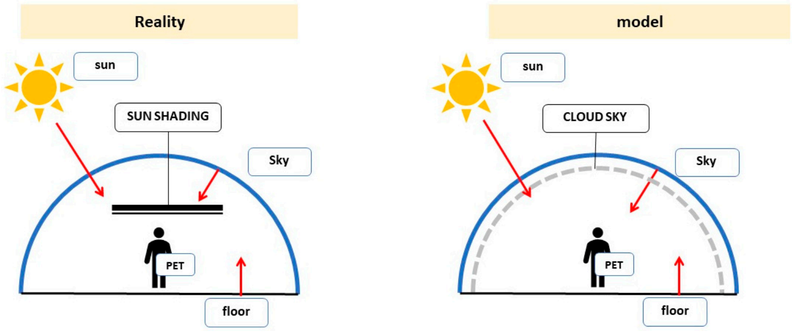


Figure 3. Cloudy sky trick implemented in RayMan to simulate the effect of sun sails on OTC.

The first step of our methodology consists in modeling the case study with RayMan, in order to both obtain the sky view factor allowed by physics obstacles and simulate the possible variations in the sky insulation index. RayMan software is a user-friendly tool used to evaluate the outdoor microclimate, which is suitable in several applications, including urban meteorology, the evaluation of health and wellbeing conditions of spaces, or their adequacy for recreation and tourism purposes. Moreover, it allows the full human energy balance (e.g., PET) to be output, while requiring a quite simple user interface. Moreover, we preferred adopting RayMan instead of other software because it allows the choice of a large range of different sky and cloud indexes. In short, RayMan allows easy calculation of the influence of the mean radiant temperature (Tmrt) on indices that measure thermophilicity, such as PET: «The model RayMan (. . .) is well-suited for the calculation of the radiation fluxes especially within urban structures, because it takes into consideration various complex horizons» [51].

To calculate T_{mrt}, RayMan considers the properties and dimensions of the radiating surface and the sky view factor in a specific point. Thus, it allows a comparison of a day where measurements have been taken with the calculated results with RayMan, which can be set by assigning different sky radiation indexes based on the amount of cloud cover. This feature is crucial for the simulation effectiveness, as «. . . in the field of urban climatology and human-biometeorology the most important question is, if the object of interest is in shadow or not».

Since RayMan calculates Tmrt point by point, as mentioned in point 2 of the methodology, we decided to simulate two floor surface temperatures, namely 37 °C and 39 °C, with the goal of discovering which role the floor Tmrt plays. An assumption was made that these were enough to show a correlation between surface temperature and the output. The case study results proved this to be correct.

Regarding point 3, RayMan allows the site location, building geometry, surface temperature, and sky view factor to be set, but it does not include options regarding possible shading devices. Given that the shading value of the cover cannot be considered, this strongly perturbs the effectiveness of the simulation outputs. Therefore, an empiric approach was adopted to consider each material as a 'cloud cover' (*Otkas* in RayMan). In other words, each technical solution suitable for making screens is considered equivalent to a sky with different levels of cloud cover, based on the features of the material adopted for shadowing. The correlation is based on an empirical approach that this study has developed which assumes clouds to reduce the sky luminance, as described by Suarez-Garcia et al. [52]. In fact, they defined a metric for this effect expressed by the Otka indicator, which ranges from 0 Otka for a 100% open sky to 8 Otka for 100% cloudy (the Otka index has no units).

Table 1 reports the correlation that has been adopted between a material's solar transmission features and corresponding cloud cover indexes, while Table 2 shows PET corresponding values, which allow the screening levels to be correlated with their effects as perceived by humans. Table 1 includes a list of possible and recurrent materials which might be selected, but they are not the only ones. The list is thus open to further integrations.

Table 1. Solar transmission and cloud cover by RayMan.

Scenarios	Materials	Solar Transmission	Cloud Cover (Otka)
1	No cover, without sun-shading sail	100%	0
2	ETFE (ethylene tetrafluoroethylene)	90%	2
3	Generic sun-shading sail not waterproof (uncoated)	30%	5
4	Tarp-curtain waterproof (PVC-coated) *	7%	7

* Coating in PVC to make the membrane waterproof.

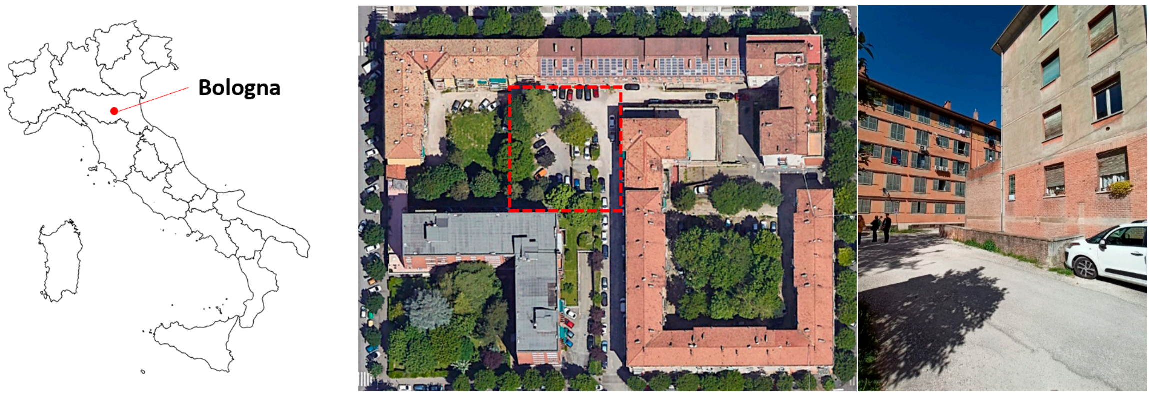
Table 2. Physiological equivalent temperature (by Matzarakis [53]).

PET (°C)	Thermal Perception	Grade of Physical Stress
>41	Very hot	Extreme heat stress
35–41	Hot	Strong heat stress
29–35	Warm	Moderate heat stress
23–29	Slightly warm	Slight heat stress
18–23	Comfortable	No thermal stress
13–18	Slightly cool	Slight cold stress
8–13	Cool	Moderate cold stress
4–8	Cold	Strong cold stress
<4	Very cold	Extreme cold stress

Point n. 4 of the methodology consists in running the simulations and comparing the results obtained for each scenario, as described in the following paragraph as clarification.

4. Case Study

The case study is located in Bologna, Italy (Figure 4a), in the middle of the Po Valley. According to the Köppen–Geiger classification [54], this area can be classified as having a humid subtropical climate (Cfa) Mediterranean climate, i.e., a humid climate with a short dry summer and heavy precipitation occurring during mild winters.



(**a**) (**b**)

Figure 4. (**a**) Bologna in the Italian peninsula. (**b**) Case study courtyard (Source: Google maps and author's archive).

The city of Bologna is a forerunner in sustainability and resilience in many fields, from climate change adaptation to the social empowerment of its citizens. Among the most important initiatives to this end, Bologna is a member of the Covenant of Mayors, is included in the 100 Climate-Neutral Cities' list, and is involved in C40 activities such as the Reinventing Cities program.

The case study, in particular, is located within the "Bolognina" district, an historic working-class neighborhood that still has one of the highest rates of social housing in the city. It comes to a high-density urban fabric with few green spaces and large impermeable surfaces. Since the neighborhood was extensively bombed during World War II, most of the buildings were rebuilt soon after, but few or no retrofitting actions were implemented in the following decades due to the chronic lack of resources of social housing agencies. This has pushed technical and functional obsolescence to critical levels, also due to the intensive use and high occupation rates of dwellings. The area has critical environmental conditions, especially for urban heatwaves and the low energy performance of buildings. In turn, these exacerbate social (fragile users) and economic issues (energy poverty, housing affordability). For these reasons, the Municipality has started a huge and ambitious regeneration plan for the entire area aimed at significantly improving livability within and the attractiveness of the district. The new town hall was also built here.

The "Ex-fuochisti" building compound that we have chosen as case study is part of that strategy, as the Municipality and Social Housing Agency (which manages the housing property) planned to convert this former warehouse into a new museum of social housing in Bologna, with the aim of revitalizing the area. The complex consists of a rectangular courtyard (20 m × 30 m) enclosed by 15 m tall buildings (Figure 4b). Currently, the courtyard is paved with asphalt and is informally used as a car park. The surrounding buildings are composed of bricks and partly covered by plaster whose finishing colors vary from light yellow to orange. Red-brownish clay roof tiles complete the envelope.

We produced a simulation of the current courtyard's microclimatic conditions in summer, as performed with the ENVI-met and RayMan software. We adopted temperature surface by ENVI-met output in two cases: with asphalt surface (current state) and grass (hypothesis). The RayMan input and boundary data are reported in Figure 5.

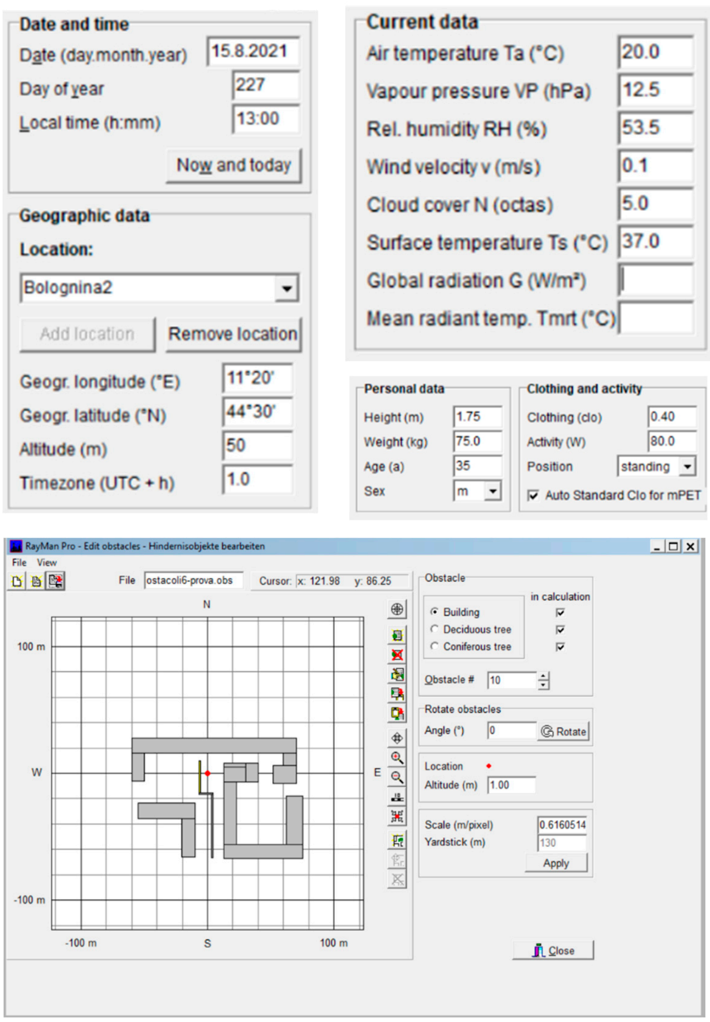


Figure 5. RayMan input and boundary data.

All simulations were carried out considering the situation of 15 August 2021 at 13:00, which was the hottest day of the previous year. The meteorological data used for the simulation are retrieved from Emilia-Romagna Regional Environmental Protection Agency (ARPAER [55]).

The overall redevelopment strategy established by the Municipality of Bologna for this area envisages replacing as much as possible the paved and dark surfaces with green surfaces (grass, shrubs, trees). However, given that the specific function of this courtyard will be a public square in front of a museum, an optimal balance must be found between permeable and impermeable surfaces. This is because a completely green area could hamper the usability of that space as a public square.

For this reason, in the early design stage, the involved architects proposed to deploy a sun-shading sail covering the courtyard, but, before developing the solution, they required a simulation of its effect in terms of achievable OTC levels. To this end, four scenarios with different shading materials were simulated through RayMan, as synthetized graphically in Figure 6.

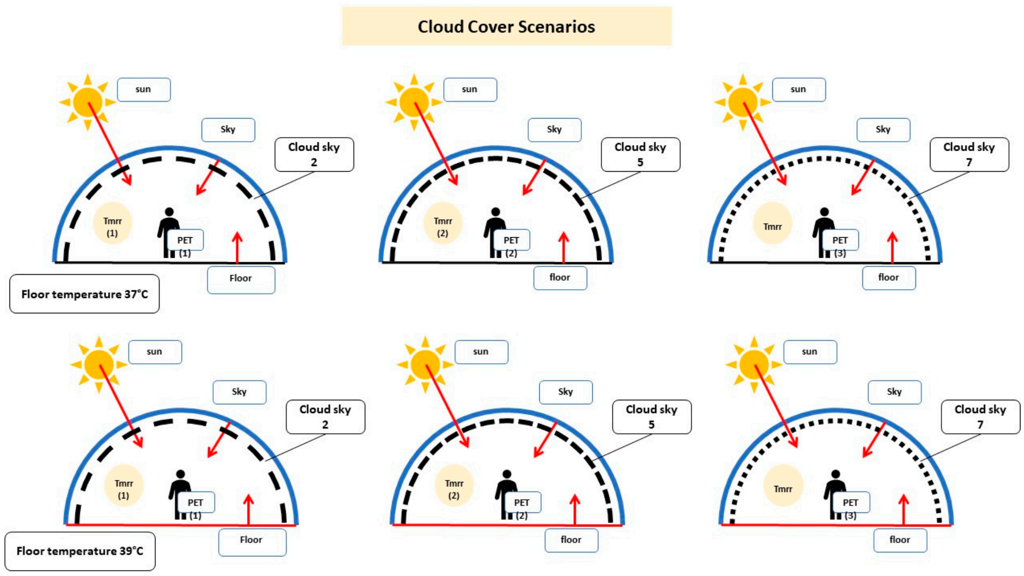


Figure 6. Sample of cloud cover scenarios that can be simulated.

The project envisaged a shading cover over the entire square, made with triangular modules of textile material supported by a network of steel cables. The steel wires are hooked to the pillars on the western edge of the square and to the facade of the Ex-fuochisti building on the east side.

5. Results

The outputs of the performed simulation included Tmrt (°C) and PET (°C) for each scenario, as reported in Table 3, and Figures 7 and 8.

Table 3. Results from RayMan simulation.

Surface Temperature	Scenarios	Cloud Cover (Otka)	Tmrt	Gap Compared to Scenario 1	PET	Gap Compared to Scenario 1
37 °C	1	0	48.7		36.1	
	2	2	47.1	−1.6 °C (−3.3%)	35.2	−0.9 °C (−2.5%)
	3	5	45.6	−3.1 °C (−6.4%)	34.3	−1.8 °C (−5.0%)
	4	7	45.5	−3.2 °C (−6.6%)	34.2	−1.9 °C (−5.3%)
39 °C	1	0	49.5		36.7	
	2	2	48.0	−1.5 °C (−3.0%)	35.7	−1.0 °C (−2.7%)
	3	5	46.5	−3.0 °C (−6.1%)	34.8	−1.9 °C (−5.2%)
	4	7	46.3	−3.2 °C (−6.5%)	34.7	−2.0 °C (−4.5%)

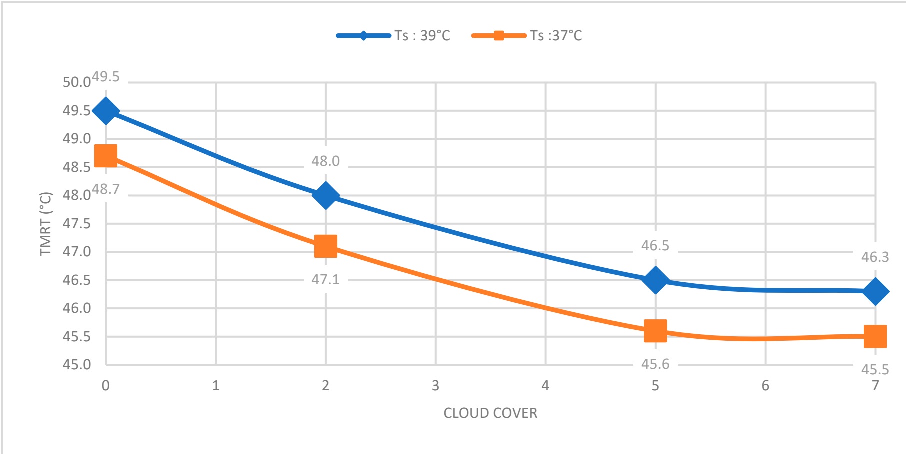


Figure 7. Correlation between mean radiant temperature Tmrt and cloud cover.

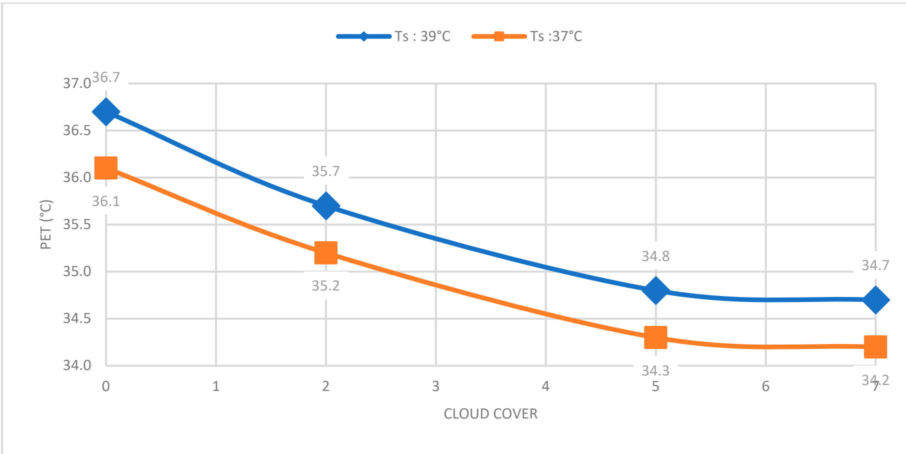


Figure 8. Correlation between PET and cloud cover.

Tmrt and PET levels decreased in each scenario, along with the decrease in the transparency of the shading material tested. The sun-shading sail improved Tmrt by around 3% and PET by 2.5% for the scenario n.2, while PVC-coated tarp (n.4) enabled a reduction in these values of 4.5% and 6.6%, respectively. Since these variations happened regardless of the floor surface temperature, we can argue that the floor surface temperature did not significantly affect the perceived comfort in this case. Thus, although the shading did not significantly change the outdoor microclimate, it allowed at least a 1 °C reduction in thermal stress associated with PET, moving it down from "Hot" to "Warm".

The results of the study we carried out showed a main role of mean radiant temperature in order to reduce PET. This is because of the energy balance equation of the human body: clouds or sun-shading reduce solar thermal radiation, which triggers a decrease in PET and correlated thermal sensation by a logarithmic trend. Moreover, the results showed a correlation between mean radiant temperature and floor surface temperature. The floor surface temperature did not play a specific role in modifying the improvement of PET values by shading scenarios. As Figure 8 shows, floor surface temperature did not influence PET trends.

It is important to point out that the human body can perceive even minor temperature variations, such as 0.5 °C [56], so the effects of the presented solutions on OTC are relevant.

6. Discussion and Limitations

When tested on the Bologna case study, the methodology provided analytical data allowing the estimation of sun-shading sail effects on OTC, thus proving that the designer(s) is capable of easily understanding the differences among the alternative design options. The stratagem of a cloudy sky was used to simulate the impact of different materials on PET and Tmrt, suggesting that this should be a way to evaluate the sky under sun-shading sails and thus filling a gap in this tool.

Sun-shading sails are a useful type of street/urban furniture technology to improve local thermal comfort, which we believe should be included in software simulations. But this is not the only one, since there are several kinds of artificial furniture or nature-based solutions [57–61] at the urban scale (e.g., floor fountains, beach umbrellas, benches, raingardens, etc.), which are difficult to model as inputs in outdoor microclimate simulation software. This might depend on the initial purpose of these software, which are often used to evaluate case studies at the urban level (e.g., urban heat island). However, these have the potential to simulate several architectural and urban scenarios at the human scale if small improvements are made. Outdoor thermal comfort evaluation needs a tool to simulate the effects at the architectural scale, such as a square, a park, or a street where urban furniture plays a key role in increasing or decreasing the presence of people in the space. A recent research project indeed shows a strong correlation between outdoor thermal comfort and the willingness of people to make use of public space [62].

In this study, the use of cloud coverage and the Otka indicator is an escamotage—a trick to "misleading" RayMan, in order to consider sun-shading covering. However, the results seem promising in correlating different materials with OTC levels, which is why we recommend integrating them in future research studies and software development.

The authors are aware that the results of the proposed methodology for simulating the effect of sun-shading sails on courtyards might benefit from a comparison with on-site monitoring, as well as that one case study alone is not statistically valid; but as mentioned, this was not the primary scope of the article, which was rather to pave the way for the development of other research projects on the simulation of sun-shading devices. Moreover, validation with real cases is not such a common practice in the field: in fact, among the large number of studies on the outdoor microclimate and urban heat island, only a few articles concern software validation with on-site measurement or from satellite or thermography by drone [63].

This study represents a first attempt to evaluate such a complex issue—which is not widely investigated and may instead have significant impacts on the understanding of outdoor spaces quality—by adopting the software RayMan. This software is already used in different fields for similar purposes and offers reliable results [51]. As the overarching goal is to raise the awareness of designers around such a complex but relevant topic for future built environments, the proposal is to bring them closer to the issue by means of a simple software/procedure, thus increasing their understanding of the effects of different materials. This may imply that some OTC variables are overlooked, or that the precision of results is not primarily considered. Other software, such as TRNSYS, would certainly provide more precise data and simulated measurements, but it would require skilled professionals to use the application and would take time to calculate the different sun-shading scenarios.

The main outcome of this study does not lie in the case study results themselves but in the proposed workflow that has been devised to evaluate the effect of diverse sun-shading materials on PET.

Although PET does not comprehensively describe OTC variations, it is widely considered the most representative and intuitive parameter for describing the scope of the investigation as reported in the article. Similarly, it has been noted that the diffused component of solar radiation is not considered at present, while it could have an impact. However, the reference outdoor microclimate physics model (e.g., Oke research [64,65]) does not yet include it, and this can be assumed as neglectable to the goal of the study. Nonetheless, further variables or indicators might be included in future stages of the research to expand and complete the study.

7. Conclusions

This article presented a simplified approach to evaluating OTC variations due to diverse sun-shading sail materials in a public courtyard.

Despite the mentioned limitations and boundaries, the proposed main goal of this study is to start a debate or prompt research on these specific issues where consistent gaps have been detected. Therefore, the strength of the study lies in providing designers with tools and procedures that are useful to support the decision-making process in its earlier stages, regarding OTC improvement through the shading of open spaces. As such, it is important to develop effective tools ensuring outdoor public spaces that are better designed and more usable by people. Different from currently available models and equations to evaluate the urban microclimate [66–69], future studies should increasingly focus on how to feature devices that are sprawling in design practice. In general, software modeling tools lack a comprehensive database, including the large variety of technical solutions currently adopted for equipping urban spaces, such as benches, rain gardens, canopies and tents, umbrellas, gazebos, and other "light" elements. Also, thanks to evaporative cooling [30,65,70–73], green infrastructures can play a role in covered public spaces, which is why it could be interesting to analyze their effects in combination with artificial materials; however, this would require a more detailed approach that was not within the scope of the presented study. In other words, in addition to the many studies addressing the urban context and urban heat islands at a large scale, design solutions at the architectural scale deserve to be further investigated.

Despite focusing on the early stages and considering only a few OTC indexes, this study attempted to initiate the process by proposing a correlation between common shading materials and Otka used by RayMan. On this basis, a simplified, easy to replicate approach for the simulation has been devised and can be applied by skilled design teams themselves. Therefore, we are confident that soon, statistical validity and on-site measurement will also be available to make the procedure sound and diffused, or at least, other researchers will be interested and further develop the topic of sun-sail shading simulations for OTC improvement.

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