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THE POTENTIALITIES OF A MULTIDISCIPLINARY APPROACH TO FAÇADE DESIGN SINCE EARLY DESIGN PHASES

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ABSTRACT

In the urban environments, façades can be conceived as public infrastructures, able to enhance not only indoor conditions, but also outdoor ones. The application of sound absorbing cladding materials has emerged as a valid design strategy to mitigate environmental noise. However, effective design solutions should simultaneously encompass different performance domains, to prevent other relevant aspects to be overlooked and potentially cause undesired effects. A broad understanding of the performance of the design alternatives during the design process is therefore essential to make performance-aware choices and achieve effective solutions in overall terms. In this study, multi-domain simulation tools are used to shed some light on the often-overlooked potential of the selection on façade cladding materials. Different material options with different sound absorbing and albedo properties were applied to the façades of two sample street canyons, in order to understand the impacts of the material choices on the environmental noise levels and outdoor thermal comfort. The results highlight that mean Sound Pressure Level (SPL) reductions up to 4 dB were found with the application of sound absorbing claddings, while high-albedo façades exacerbate the thermal stress perceived by pedestrians, with mean increases in Physiological Equivalent Temperature (PET) of about 2.5-3.5 °C.

1. INTRODUCTION

Given the future perspective of climate change and increasing urbanization, the enhancement of thermal and acoustic comfort conditions are some of the main challenges that cities need to address to promote public health and well-being [1], [2].

According to the World Health Organization (WHO), between 2030 and 2050 climate change is expected to cause approximately 250,000 additional deaths per year due to malnutrition, malaria, diarrhea and heat stress [2]. In cities, the urban heat island (UHI) phenomenon, exacerbates the impact of global warming, thus threatening the health of its inhabitants and increasing energy demand for cooling [2], [3]. Therefore, the enhancement of outdoor thermal comfort in cities would promote the well-being of the urban population and increase the attractiveness of open spaces [4], while also contributing to energy savings by reducing the reliance on active systems to achieve thermal comfort in the indoors. As evidenced by the WHO, the well-being of urban populations is also threatened by the increased health risks due to environmental noise pollution (e.g. cardiovascular disease, cognitive impairment in children, sleep disturbance, tinnitus and annoyance) [1]. In order to protect the public health in cities, the WHO has suggested thresholds of outdoor sound pressure levels not to be exceeded in cities [1]. Moreover, low environmental noise levels would allow dwellers to stay comfortably indoors with open windows.

Despite the growing interest towards noise pollution and outdoor thermal comfort, these themes are generally not taken into account during design processes [5], [6]. The decisions about urban form and building fabric have long-lasting, cumulative impacts on the liveability of urban open spaces, and on the use of energy in buildings [7]. Both environmental noise levels and outdoor thermal comfort in urban open spaces are influenced by the morphological and material properties of the surrounding urban fabric. The compact layout of urban environment and the sound reflective properties of common construction materials cause the environmental noise levels in cities to increase due to multiple reflections. At the same time, outdoor thermal comfort depends on the different microclimatic conditions within the urban canopy layer, which are influenced by both the geometric and material properties of the surrounding urban elements.

Previous studies have investigated the potential of the geometrical and material features of façades [8]–[13] as environmental noise reduction strategies. A recent review article has collected the main findings of the studies related to façade design features [14]. Based on previous works, sound absorbing materials applied to urban facets lower environmental noise levels by reducing the amount of sound reflections occurring in the urban environments. Although most sound absorbing materials are designed for indoor spaces, sound absorbing solutions suitable for outdoor applications have started appearing on the market (e.g. porous concrete, foam glass).

Other studies have suggested design solutions able to enhance thermal comfort in outdoor urban spaces, considering the geometrical and material features of urban fabrics or the use of vegetation; comprehensive reviews of these mitigation strategies can be found in [15], [16]. With respect to material features, the application of high-albedo or “cool” materials on building envelope was advanced. Thanks to their high solar (i.e. shortwave) reflectance and high infrared (i.e. longwave) emittance, high-albedo materials maintain lower surface temperatures with respect to conventional ones. Since visible light is included in the shortwave range, typically high-albedo materials present a light color, while low albedo materials feature a dark color. However, solar reflective nonwhite surfaces are also available [17]. High-albedo materials are used to reduce building energy demand for cooling and to mitigate UHI, i.e. reducing outdoor air temperature. The lower surface temperature of high-albedo materials results in less heat transferred to the building interior, in a reduced amount of heat exchanged with the air, and in lower longwave radiation emitted by the surface. Recent studies have investigated the impact of such materials on outdoor thermal comfort conditions, suggesting that the resulting increase in reflected solar radiation may offset the reduction of emitted radiation and thus increase thermal discomfort in urban open spaces [17]–[19].

Building façades are generally conceived without considering their influence on outdoor conditions. However, as interfaces between indoor and outdoor environments, they can influence, and potentially benefit, both conditions. As also suggested in [20], building façades, if properly conceived, can be also serve as public infrastructures, able to promote public health in cities. While urban morphology can hardly be altered in the built environment, retrofit interventions on existing building façades are commonly implemented mainly to enhance the energy efficiency of the buildings. While vertical surfaces have the largest impact over the thermal comfort perceived by pedestrians [18], and play a major role in the multiple sound reflections occurring in the urban environment, normally architects do not consider the potential implications of the properties of façade cladding materials on outdoor thermal and acoustic comfort conditions. A multidisciplinary design approach, in which relevant information on different performance goals is available to the designers since early design phases, would help maximizing the effectiveness of building façade design. Early design decisions have the largest impact over the final performances, and therefore it is crucial to take performance-aware decisions [21].

1.1 Objectives

This study presents a parametric investigation of the influence the acoustic and radiative properties of façade cladding materials on outdoor acoustic and thermal comfort conditions in the urban environment. The effects of different cladding materials applied to the façades of the side buildings of a street canyon have been analyzed by means of computer simulations. Specifically, the research focuses on the variations of outdoor environmental noise levels and of outdoor thermal comfort conditions perceived by dwellers and pedestrians resulting from the variation of the sound absorbing properties and the albedo of the façade claddings of the buildings in two street canyons with different height to width (H/W) ratios. The analyses were carried out considering a typical summer day in Turin and with leisure noise due to the presence of people talking in the street.

The research aims also to suggest a multidisciplinary design approach for early phases applications that could increase the designers' awareness on the multi-domain implications of the design decisions and allow them to make informed choices.

2. RESEARCH METHODOLOGY

Acoustic simulations run in Pachyderm Acoustics and microclimatic simulations run in ENVI-met were used to estimate the effects of the different design modifications considered in this study. A case-study building in Turin and the street portion in which it is located have been used for the analyses. The change in material properties, i.e. surface albedo and sound absorbing properties, were applied to the opaque components of the façades of all the building at the sides of the street. The influence of the material variations on outdoor thermal and acoustic comfort was evaluated in outdoor positions at different heights over the façade of the case-study and opposite buildings, to describe the conditions of dwellers, and at the street level, to describe that of pedestrians. Coherently with the thresholds suggested by the WHO [1], the A-weighted Sound Pressure Level (SPL(A)) has been used to quantify the environmental noise levels as indicator of outdoor acoustic comfort conditions, while the Physiological Equivalent Temperature (PET) and Mean Radiant Temperature (T_{mrt}) were used to describe the outdoor thermal comfort conditions.

2.1 Description of the case-study building façade and street canyon

A portion of Via Saluzzo in Turin (Italy), which is a typical street canyon of the city and has been object of a previous study [8], was selected for investigation (Figure 1).

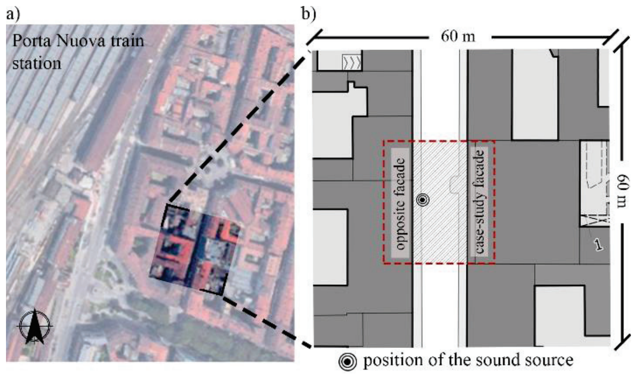

Figure 1. (a) map of the area in Turin where the street canyon is located; (b) map of the urban portion of considered in the thermal simulations with the case-study building colored in red.

The area is characterized by high levels of leisure noise during nighttime, due to the presence of people talking in the outdoor terraces of pubs and restaurants or directly in the streets. For the purposes of the presented analysis, the actual street orientation, shown in Figure 1a, has been slightly modified to be perfectly N-S oriented, as shown in Figure 1b. All the buildings in the model domain feature concrete walls with moderate insulation, while the changes in albedo and sound absorption properties are referred to their exterior claddings. These changes have been applied to all the opaque parts of the building façades included in the street portion. To assess the effect of changes in the H/W ratio of the canyon, the actual street width (10m, corresponding to H/W ratio of 1.4), has been halved (5m, corresponding to H/W ratio of 2.8). The simulation results have been collected only in the central section of the urban canyon, to prevent the result from being affected by the finite dimensions of the modelled area. The stringent geometrical simplification required by ENVI-met (i.e. all elements must be modeled according to a regular 3D grid) were also applied to the model fed to Pachyderm Acoustics, to ensure coherency between the two analyses. This implies that the entire model geometry has been approximated with a resolution of 1m.

The case-study building is located at the center of the analyzed street portion and its main façade faces west; the building has been object of a previous investigation in [8]. Slight design modifications were applied with respect to the actual building façade considered in [8], to ensure coherency among the models fed to the two simulation tools and to obtain more generalizable results to comply with the parametric nature of the study.

As a result, the modeled building features 4 floors above ground, with commercial activities at the ground floor (height = 4m), and residential units at the three upper floors (each one with a height = 3m). The alternated pattern of balconies at the second and third floors of the actual building were not modelled for the purpose of this analysis. Its façade is shown in Figure 2; it features five showcases at the ground floor, while 12 glass doors (height = 2m; width = 1m) are present at each residential floor to simulate the presence of Juliet balconies. Overall, the façade features of 14m and a width of 25m.

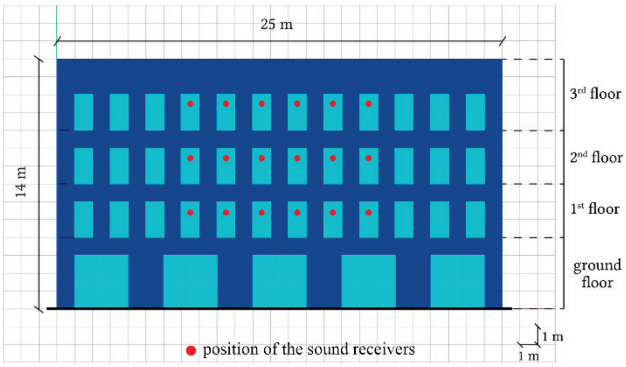

Figure 2. Case-study building façade with sound receivers' location.

2.2 Acoustic simulations

The performance simulations were performed using the Grasshopper version of Pachyderm Acoustics (version 2.0.0.2), a geometric acoustic based tool integrated in Rhinoceros which combines image source and ray-tracing methods. The acoustic properties of the materials of the model have been calibrated with respect to the reverberation time (T_{30}) measured in situ; further details on the calibration procedure can be found in [8]. Despite the slight design modifications described in Section 2.1, the model calibration in [8] is considered valid.

The simulations were performed with a cut-off time of 5000ms and transition order 1. Based on the sensitivity analysis in [8], these settings were identified as the most suitable to balance calculation time with the accuracy of the results ($\Delta SPL < JND_{SPL}$ of 1dB [22]). The optimal number of rays was automatically identified by Pachyderm, based on the convergence of the results.

Since leisure noise is the prevalent noise source in the district considered, the virtual source was modelled to simulate a group of people talking in the street. Therefore, an omnidirectional sound source has been set at a height of 1.6m in a central position over the opposite sidewalk with respect to the case-study building, in correspondence to an outdoor terrace. The sound power spectrum was extracted from the recording of a group of 6 people talking in situ, with negligible light traffic noise in the background; further details can be found in [8]. It must be noted that, while the aim of this study is to evaluate this specific scenario, the most relevant environmental noise source worldwide is road traffic [1], which is characterized by lower frequencies and should be modeled as linear source.

To evaluate the acoustic comfort of dwellers, 27 sound receivers were set in outdoor positions located in correspondence to the 1st,2nd and 3rd floors of the case-study building (18 receivers) and of the opposite one (9 receivers). The receivers are distributed over equally dimensioned portions of both buildings and street. The receivers over the façades are set in correspondence of the windows, at an height of 1.65m from the respective building floor level and at a distance of 0.6 m from the windows, in compliance to the ISO 1996-2:2007 Standard [23]. Moreover, to assess the acoustic comfort of pedestrians, a grid of 18 receivers was set at the street level at a height of 1.65m, with two lines of 6 receivers over the two sidewalks (at a distance of 0.6m from the closest façade) and one line along the street centerline. The distribution of the receivers on the case-study building is shown in Figure 2, while that of receivers over the opposite building and at the street level and the sound source position is shown in Figure 3. The A-weighted Sound Pressure Level (SPL(A)) was used to describe the environmental noise perceived by the human ear in the receiver positions. Usually SPL levels are used to describe the objective acoustic conditions of outdoor spaces.

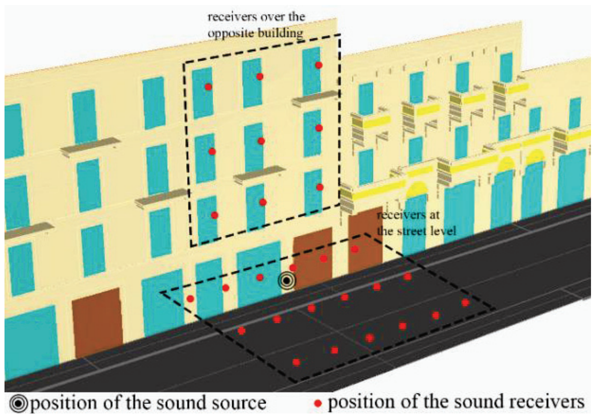

Figure 3. Position of the sound source and receivers over the opposite building and at the street level (1.65m agl).

2.3 Microclimatic simulations

The microclimatic simulations were performed in ENVI-met (version 4.4.5) using a grid resolution of 1m x 1m x 1m with a model domain of 60 x 60 grids in plan and 24 grids in height. A 10% telescopic factor has been applied for heights above that of the highest building (14m) to ensure that the model height is at least two times that of the highest building. Moreover, 4 nesting grids were set around the model domain. A 48h time span has been used to run the simulation to ensure the stability of the results; only results from the last 24 hours were considered. Weather data was collected from ARPA Piemonte meteorological stations of Torino Vallere for air temperature and relative humidity, and of Reiss Romoli for solar irradiation for a typical summer day in Turin (i.e. July 19th 2018). This data was used to define the meteorological boundary conditions for the model using the simple forcing module of ENVI-met. For the sake of simplicity, the case-study building façade was modelled with both opaque and transparent surfaces (i.e. windows), while the remaining ones feature opaque materials only. In in the T_{mrt} calculation procedure of ENVI-met the radiative properties and the surface temperatures are averaged over all the façades in the model domain. Therefore, to prevent this feature to influence the T_{mrt} results in the canyon, the material changes were applied to the opaque parts of all the façades in entire model domain.

Due to the 3D grid discretization of ENVI-met, the outdoor thermal comfort conditions of pedestrians in the street section facing the case-study building were calculated at 1.5m agl, which approximates the human-biometeorological reference height of 1.1m agl, as done in [18]. Moreover, also the comfort condition in outdoor positions over the façades were evaluated, to account for the perception of dwellers in the Juliet balconies. The index used to describe outdoor thermal comfort is the Physiological Equivalent Temperature (PET), which is calculated by BIO-met from data related to the air temperature (T_a), mean radiant temperature (T_{mrt}), wind speed and relative humidity. PET is defined as the air temperature at which, in a typical indoor setting (without wind and solar radiation), the heat budget of the human body is balanced with the same core and skin temperature as under the complex outdoor conditions to be assessed [24]. PET values were calculated with the standard settings of BIO-met, i.e. for a 35 years old man, with the following parameters: height = 1,75m; weight = 75kg; static clothing insulation = 0.9clo; metabolism=1.48met. Moreover, since T_{mrt} is the physical variable that influences outdoor thermal comfort the most, it has been also evaluated.

2.4 Design variations

The design variations applied to the building façades and to the street canyon are the following:

a) Variation of the weighted sound absorption coefficient (α_w) of the material applied to the opaque surfaces of the building façades: 0.2 and 0.8
b) Variation of the albedo (ρ_{sw}) of the material applied to the opaque surfaces of the building façades: 0.2 and 0.8
c) Different street canyon widths, i.e. 5m and 10m, resulting in H/W ratios of 2.8 and 1.4, respectively.

The above-mentioned changes are summarized in Figure 4. The radiative and acoustic properties of the materials are considered representative of common construction materials. Two archetypal materials with either sound reflective (i.e. low level of sound absorption) or sound absorbing properties were selected. The sound absorption coefficients of the two materials are detailed in Table 1 along the frequency spectrum and as weighted sound absorption coefficient (α_w), calculated according to the ISO 11654 Standard [25].

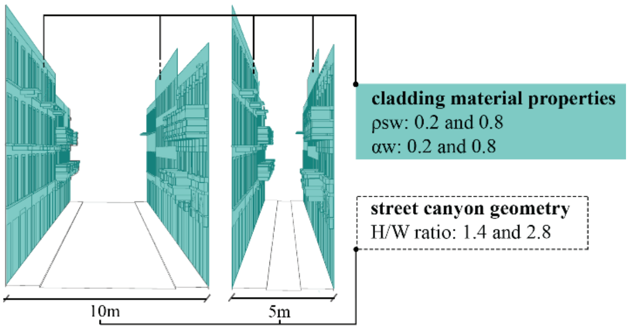

Figure 4. Geometrical and material changes considered in the analyses.

3. RESULTS AND DISCUSSION

In the Figure 5a and 5b, the mean A-weighted SPLs and the corresponding standard deviations obtained for the two cladding material absorption a_w, are reported for the canyon with H/W ratio 1.4 and 2.8, respectively. The SPLs plotted are the average values with respect to the receivers at the different floors of the case-study building (CS), of the opposite one (OB) and with respect to the three receivers' lines at the street level (ST).

SPLs are systematically greater in the narrower canyon (H/W ratio = 2.8). This can be seen clearly when the façades are treated with sound reflective materials (a_w= 0.2), where in the narrower canyon the SPLs on the case-study façade are on average 3.1 dB greater than in the wider canyon (H/W ratio = 1.4). This trend is slightly less noticeable for absorbing cladding materials (a_w=0.8), where SPLs are greater on average by 1.8 dB.

SPLs decrease with height due to larger sound-receiver distances. The SPL decreases found with increasing height are more noticeable on the opposite façade than in the case-study one in the street canyon with H/W ratio of 1.4. Such difference is attenuated in the narrower canyon, where the SPLs decrease with similar trends on both buildings, due to the effect of multiple reflections.

The enhancement of the absorptive properties of the cladding materials result in decreases in SPLs in all the configurations and positions analyzed. The SPL reductions due to the increased absorption are more noticeable in the narrower canyon, and are greater on the opposite building (mean ΔSPL = 2.9 dB and 3.9 dB for H/W ratio of 1.4 and 2.8, respectively) than on the case-study one (mean ΔSPL = 1.5 dB or 2.9 for H/W ratio of 1.4 and 2.8, respectively).

material level of sound absorption	octave band central frequency [Hz]								a_w
	63	125	250	500	1000	2000	4000	8000	
low	0.04	0.04	0.08	0.15	0.18	0.18	0.20	0.20	0.20
high	0.26	0.26	0.50	0.90	1.00	1.00	1.00	1.00	0.80

Table 1. Sound absorption coefficients and weighted sound absorption coefficient of the cladding materials considered in the study.

This is probably due to the asymmetrical position of the sound source in the canyon, which cause the receivers over the opposite façade to catch the sound energy specularly reflected by case-study building and consequently make the SPLs in those positions more sensible to changes in the sound absorption properties of its cladding. On the other hand, the sound specularly reflected by the opposite façade are not directed towards the receivers over the case-study building, due to their large angle of incidence. The SPL decreases due to absorption tend to be slightly more noticeable at the upper floors.

At the street level, the SPL reductions due to the sound absorbing claddings are negligible ($\Delta SPL < JND_{SPL}$), while the differences in mean SPLs among the three receivers' lines are due to their different distance from the source. Indeed, sound reflections over building façades does not seem to play a major role in the sound energy caught by receivers at the street level.

These results further confirm the mitigation potential of sound absorbing façade claddings with respect to the environmental noise level perceived by dwellers, suggesting that their effectiveness is greater in compact urban scenarios, as narrow street canyons. Despite the benefits provided to dwellers, sound absorbing façade cladding result ineffective in lowering the environmental noise levels perceived by pedestrians.

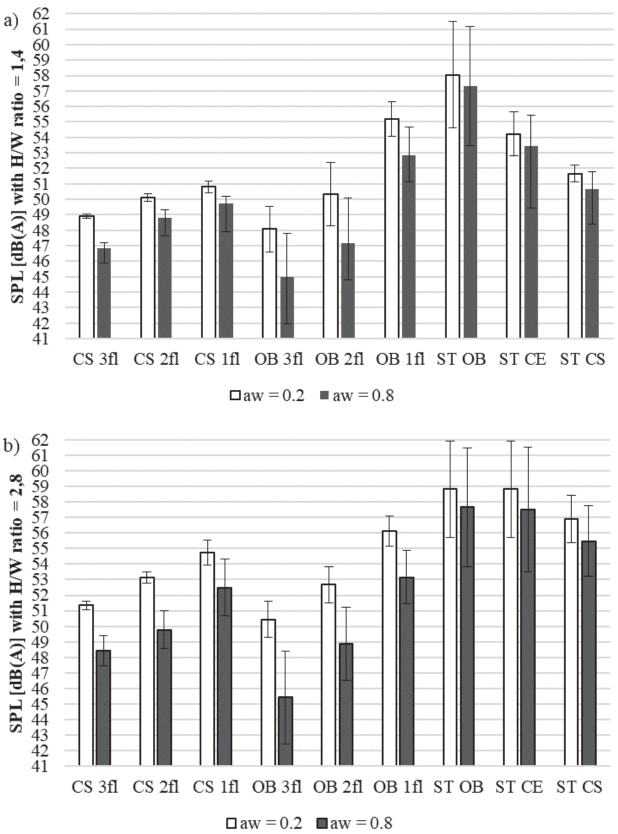

Figure 5. Mean SPLs in outdoor positions at the different floors over the case-study (CS) and opposite (OB) buildings, and at the street level in correspondence to the opposite sidewalk (ST OB), street centerline (ST CE) and case-study sidewalk (ST CS) for a street canyon with H/W ratio of either 1.4 (a) or 2.8 (b).

The results of the microclimatic simulations have been collected considering the hourly variation of the PET and T_{mrt} values from 7:00 to 19:00 in the center of the street portion facing the case study building in Figure 6a, and in an outdoor position over the case-study façade, in correspondence to the second floor, i.e. at 1.1 from the second floor level, in Figure 6b.

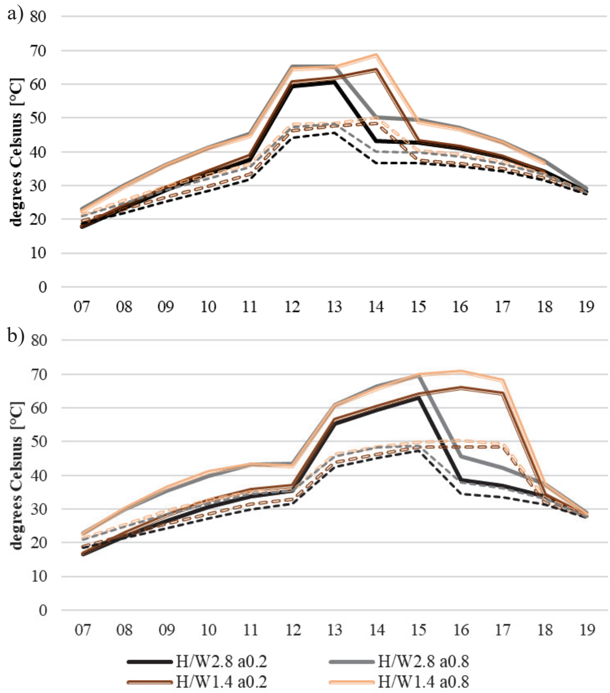

Figure 6. Hourly variation of T_{mrt} (solid line) and PET (dashed line) for either 0.2 or 0.8 of albedo and either 1.4 or 2.8 as H/W ratio at the street level in a central position with respect to the case-study building over the street centerline (a) and in an outdoor position at the second floor of the case-study building (b).

The T_{mrt} and PET patterns are influenced by the rate of solar radiation received during the day at the calculation points. In particular T_{mrt} and PET values reaches the highest values when the calculation points in the two canyons are exposed to direct solar radiation, with T_{mrt} varies in the range of 55-70°C and PET varies in the range of 45-50°C. During the day, the wider canyon is exposed to direct solar radiation for a longer period, so T_{mrt} and PET are in the mentioned ranges for 1 to 2h longer than in the narrower canyon, depending on the calculation positions.

For the different H/W ratios and calculation points, the relative variation of T_{mrt} reported for the two values of cladding albedo follows similar trends. However, for the high-albedo claddings (ρ_{sw}=0.8) T_{mrt} values are systematically greater than those with ρ_{sw} equal to 0.2 in the entire time frame under analysis. At the street level, the T_{mrt} for high-albedo claddings is on average 4.5°C greater for H/W ratio of 1.4, and 5.7 °C greater for H/W ratio of 2.8. In the outdoor position in correspondence to the second floor of the case study building, the T_{mrt} for high-albedo claddings is on average 5.4°C greater for H/W ratio of 1.4, and 6.7 °C greater in the canyon with H/W ratio of 2.8. Indeed, the increased solar radiation reflected by the façade surfaces offsets the reduction in longwave radiation emission due to their lower surface temperature (for high-albedo a smaller fraction of solar radiation is absorbed and therefore the surface temperature and the longwave radiation emitted is lower). The PET follows similar trends to T_{mrt}, and greater PET values are found when building façades are cladded with high-albedo materials. This confirms that the greater T_{mrt} values found in these conditions corresponds to a warmer thermal sensation for both pedestrians and dwellers. The mean increase in PET due to the high-albedo cladding materials for both dwellers and pedestrians is 2°C for H/W ratio equal to 1.4, and 3°C for H/W ratio equal to 2.8. These results are coherent with the findings of other studies, such as [17]–[19], that evidenced the exacerbation of heat stress caused by high-albedo materials. The trend is present also when the canyon is not exposed to direct solar radiation and is only exposed to diffuse sky radiation, while in such conditions no significant difference in T_{mrt} and PET is reported between the narrower and wider canyons. As it can be noticed, the increases in T_{mrt} and PET due to the application of high-albedo materials on the façades are more evident for the narrower street canyon, due to trapping of the shortwave reflections. The mean T_a decrease from 7:00 to 19:00 (omitted in Figure 6) due to the high-albedo façades is 0.1°C for all the combinations of H/W ratios and calculation points.

In the attempt to assess the influence of the cladding material albedo on outdoor thermal comfort, further analyses were performed considering the time of the day in which only the west-oriented part of the canyon is sunlit while the street level is in the shade, i.e. no direct solar radiation is present. This condition occurs at 15:00 for the canyon with H/W ratio equal to 1.4 and at 14:00 for H/W ratio equal to 2.8. In this way the contribution of the radiative fluxes reflected (for the shortwave part) and emitted (for the longwave part) by the sunlit façades at the street level could be evaluated for the different albedo values. Figure 7 and Figure 8 map the distribution of the PET and T_{mrt} values at the street level and in the street section, when only the west-oriented façades are sunlit.

The results show that in such conditions, with the application of high-albedo cladding materials, the T_{mrt} at the street level is 5-6 °C higher in case of H/W ratio of 1.4 (i.e. wider canyon) and 6-7°C higher in case of H/W ratio of 2.8 (i.e. narrower). The observed T_{mrt} increases lead to increases in PET generally in the order of 2.5-3.5°C for the wider canyon. The increase in PET at the street level is slightly more evident in case of the narrower canyon. With respect in the street section, the application of high-albedo façade cladding leads to increased T_{mrt} and PET in the entire street section up to the building roof level. The greatest increases (ΔPET=3.5-4.5°C and ΔT_{mrt}=7-8°C)

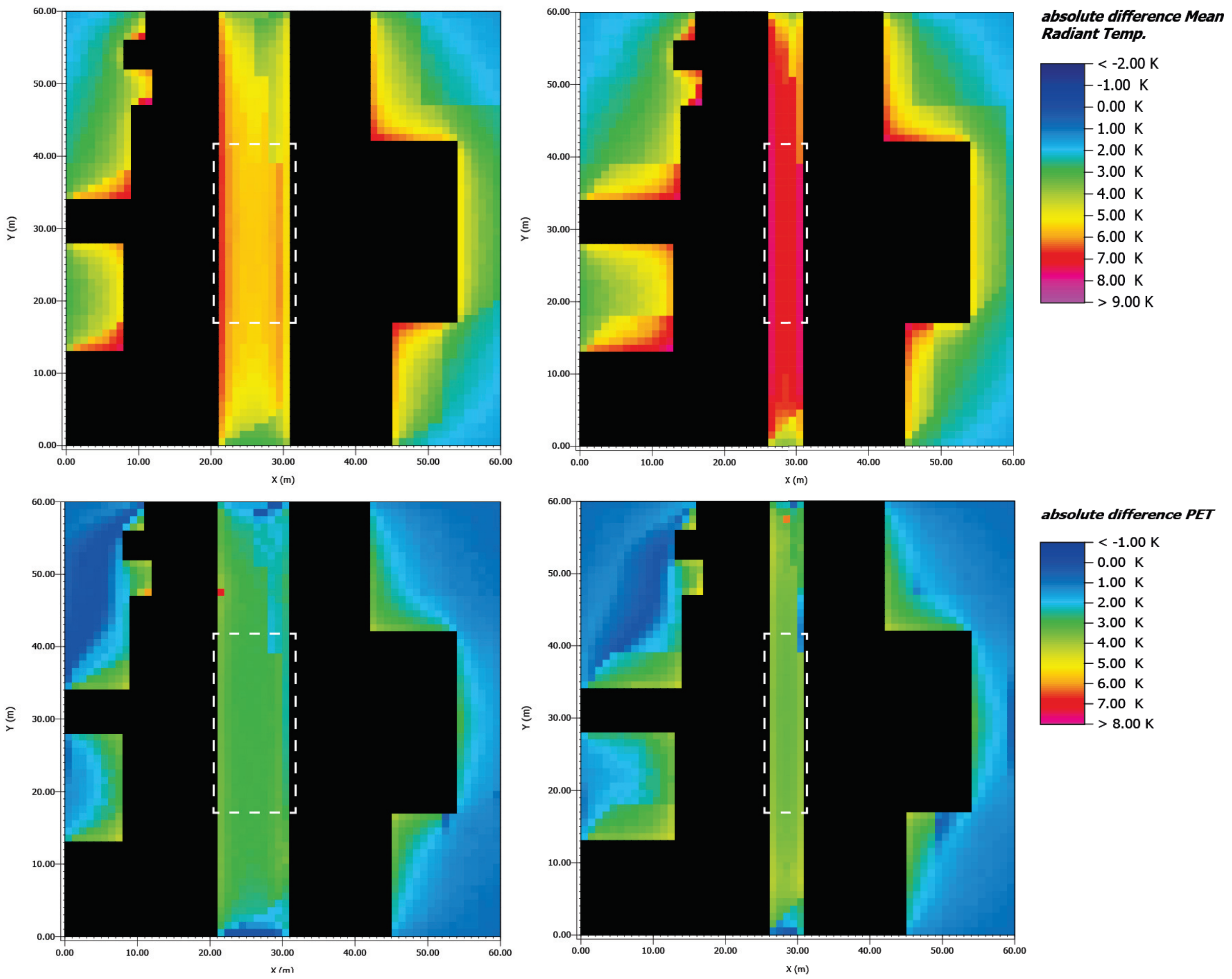

Figure 7. Absolute differences in PET and T_{mrt} a height of 1.5m from the street level, at 15:00 for H/W ratio of 1.4 and at 14:00 for H/W ratio of 2.8. Only results included in the white rectangles are considered valid.

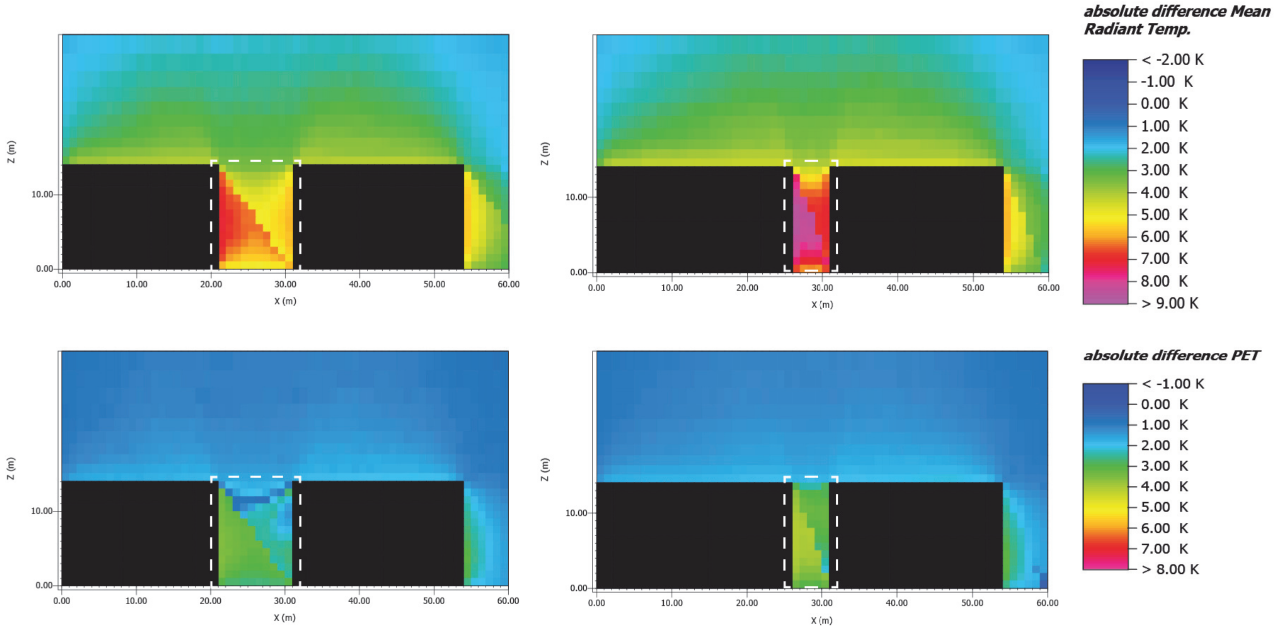

Figure 8. Absolute differences in PET and T_{mrt} in the street section set at the center of the case-study façade, at 15:00 for H/W ratio of 1.4 and at 14:00 for H/W ratio of 2.8. Only results included in the white rectangles are considered valid.

are found in the opposite façade, which is not exposed to direct radiation, but report an increase in T_{mrt} and PET values due to the solar radiation reflected by the sunlit case-study façade cladded with high-albedo materials. In coherence with what previously observed the application of high-albedo materials lead to higher T_{mrt} and PET values in the narrower canyon, due to the greater amount of shortwave reflections occurring for high ρ_{sw} values.

Overall, these findings evidence the often-overlooked consequences of the application of high-albedo materials over building façades. While being established solutions to mitigate UHI and reduce energy demand in buildings, they can exacerbate heat stress in their surroundings, especially in compact urban environments. Therefore, it is crucial to consider these implications when choosing cladding materials of the façade and, more generally, to carefully select the surfaces to treat with high-albedo materials in order to increase building energy efficiency without increasing the heat stress in their surroundings. In this way it is possible to increase the ability of cities to better cope with the challenges posed by climate change, allowing building design to contribute to both climate mitigation (by promote energy savings) and adaptation (by enhancing outdoor thermal comfort) in the urban environments.

4. CONCLUSIONS

This paper focuses on the potential benefits provided by façade design to the outdoor urban environment, which are often only marginally considered during design processes. In particular, the effects of changing the albedo and the sound absorption properties of the materials of the façades have been analyzed in two street canyons, considering the resulting changes in the outdoor thermal comfort conditions (described by PET and T_{mrt} values) and in the outdoor sound pressure level (described by SPL(A)) perceived by pedestrians and dwellers. The results highlight the benefits provided by sound absorbing façade claddings, especially in narrow street canyons, where mean SPL(A) reduction up to 4 dB were found over the building façades. The application of high-albedo materials to the façades generally increase the radiative fluxes at the street level, due to the increased fraction of solar radiation reflected by them. This effect is exacerbated in the narrower street canyon, where T_{mrt} increases in the range of 6-7°C are reported at the street level, which resulted in PET increases of about 3.5°C. This trend is shown also outdoor positions over the façades, where higher T_{mrt} and PET values were found in case of high-albedo façade claddings. These increases are particularly evident over the shaded façade of the canyon, when the opposite side is sunlit and reflects solar radiation over the shaded area.

These results highlight the importance of the adoption of a holistic approach to design problems since early design phases. By encompassing difference performance domains, designers are able to gather relevant information and control the often-overlooked performance implications of the design choices. Given the long-lasting impacts of architectural and urban interventions, this approach would help optimizing their beneficial effects, allowing cities to better cope with the future challenges posed by climate change and increased urbanization.

Further studies may analyze the combined effect of geometrical and material changes of the building façades, consider a broader variety of street orientations and H/W ratios, and include the assessment of performance goals related to the indoor spaces, as energy demand for HVAC. Moreover, additional analyses can be performed considering traffic noise, winter scenarios and evaluating other soundscape parameters.

5. REFERENCES

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