Exploring the impact of the urban modified albedo on the indoor temperature and the ventilative cooling potential in a typical Italian residential building

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ABSTRACT

Urban heat island, with the associated urban overheating, is a well-documented phenomenon, which demonstrates the hazard related to local climate change and the related negative impacts at environment, economic, social and public health level, with heavier consequences on the low income and more fragile segment of the population. The phenomenon takes origin by the positive thermal balance in the urban built environment mainly, depending on the synergic effect of different causes. It is also associated with a typical atmospheric circulation, playing a significant role in local dispersion processes. The interaction of local and global climate change exacerbates the thermal quality of cities, with more frequent and more intense extreme events, being the heat waves the most relevant. Several solutions exist to counteract urban overheating, and three main categories are identified: blue (water), green (vegetation) and white (materials) technologies. The present study investigates the potential of ventilative night cooling improvement in residential buildings in the city of Rome, Italy, by dynamic analyses carried out at mesoscale and building level. Initially the land and atmospheric models of the city are implemented in the Weather Research and Forecasting model, in a next phase the whole model was validated against the near surface temperature and wind speed ground measurements., Then, a number of different albedo scenario is defined and simulations are run for the hottest months (July and August) of the year 2020. The so obtained weather data set are used as input to simulate the thermal performance of a typical residential Italian buildings using TRNSYS 17 software, with a dedicated routine based on a simplified model to take into account the contribution of the natural ventilation. The operative temperature is the key performance indicator for the analyses and the number of discomfort hours, calculated according to the relevant standard, are used to quantify the impact of the urban modified albedo on the thermal response of residential buildings.

KEYWORDS

Mesoscale simulation, night ventilation, thermal comfort, building energy simulation

1 INTRODUCTION

Urban heat island, with the associated urban overheating, is a well-documented phenomenon, which demonstrates the hazard related to local climate change and the related negative impacts at environment, economic, social and public health level, with heavier consequences on the low income and more fragile segment of the population. The phenomenon takes origin by the positive thermal balance in the urban built environment mainly, depending on the synergic effect of different causes: absorption and storage of solar irradiation by the construction surfaces, the anthropogenic heat, the reduced evapotranspiration and surface permeability due to the lack green and natural areas, change and reduction of urban ventilation (Oke et al., 1991). It is also associated with a typical atmospheric circulation, playing a significant role in local dispersion processes (Falasca et al., 2013). The interaction of local and global climate change

exacerbates the thermal quality of cities, with more frequent and more intense extreme events, being the heat waves the most relevant (Perkins, 2015).
Several solutions exist to counter urban overheating, and three main categories are identified: blue (water), green (vegetation) and white (materials) technologies (Akbari et al., 2015). The latter solution gained interest in the past three decades with the development of the cool materials, characterised by high albedo (also called solar reflectance, when referred to specific materials rather than to large areas) and thermal emissivity, which minimise the solar irradiation absorbed by the construction surface and easily dissipate the residual stored heat by radiation (Santamouris et al., 2017). Cool roofs use white or selective cool coloured materials, being the latter characterised by a very high reflectance in the near-infrared range while keeping the design colour in the visible range. The benefit of the technology is well documented by numerical analyses and field studies (Testa & Krarti, 2017). Mesoscale simulations have been recently introduced to predict the mitigation impact of higher albedo materials in cities, trying to understand potentials and risks of the application at large scale (Falasca et al., 2019).
The impact of different urban albedo scenario on the improvement of the cooling energy performance of a residential building was analysed by dynamic analyses carried out at mesoscale and building level for the City of Rome (Italy) in (Falasca et al., 2024). The objective of this study is to carry out a similar analysis for residential buildings without active cooling and naturally ventilated. As per in the previous study, the application of an innovative configuration of the Weather Research and Forecasting (WRF) model was specifically implemented for the city of Rome. In addition, the observation period was here extended to two entire months to cover the hottest period of summer.

2 MATERIALS AND METHOD

The study is structured in the following phases:

I. Implementation of the city land and atmospheric model, and successive validation against the measured air temperature and wind speed in a selected site.
II. Identification of the modified urban albedo scenarios in line with (Falasca et al., 2024), next the meso-scale simulations for the reference and the variant scenarios are run for the months of July and August 2020.
III. Identification and modelling of the reference building and of the natural ventilation strategies, and thermal calculation of the building in thermal free floating condition in transient regime.
IV. Calculation of the indoor operative temperature for all the building configuration, and assessment of the change in the indoor thermal comfort conditions due to heat mitigation caused by the increase of the urban albedo.

2.1 The case study area

Rome, the capital and largest city of Italy, is in the middle of the Mediterranean basin, and it belongs to the Csa class (Mediterranean climate) according to the Köppen-Geiger climate classification. It is one of the largest Mediterranean metropolises with 2.85 million inhabitants, peaking 4.6 million if all the metropolitan area is considered. The municipality extension is about 1290 km² and a density of about 2200 inhab./km².
The green areas within the city borders account to more than 60% of all territory, which is exceptionally high in comparison with the other metropolis of the region. Such areas are, however, essentially located in the extreme periphery of the municipality, while urban green areas account only for the 3.1% of the city surface. This aspect, as well as the complex, dense and stratified urban texture, makes the city highly vulnerable to urban heat island and overheating (Zinzi et al., 2018).

2.2 The reference urban setting and its variants

A reference case and three variants simulating the application of high albedo materials in the urban area of Rome are defined and then simulated through the Weather Research and Forecasting model (WRF, described in detail in Section 3.1). The reference case is based on the database present in the WRF model for the footprint share of green areas, pavements and roof within the city boundaries. The model includes the buildings and streets' size as a function of urban typologies, as well as the solar reflectance (albedo) of the construction materials for the current urban dataset. The latter is reported in Table 1 with the values of the three variants. Reflectance values for V3 correspond to state of the art solutions available on the marked, such as light grey concrete, treated with light coloured aggregates and binder, for pavements and white coating and tiles for roof. Intermediate values are selected accordingly: V1 doubles the reference values, next the increase in reflectance are 0.1 and 0.2 for urban surfaces and roofs, respectively. To be noted that thermal properties of materials (e.g., albedo, thermal emissivity) are the same throughout the built area, regardless of the urban typologies (for more details see Section 3.1); the thermal emissivity is 0.9 in all cases, as it is very high for all the construction materials but metals, thus it does not change for the selected scenarios.
The calculations of the building thermal response are carried out using the four weather data data-set, referring to the reference case and to the three identified modified urban albedo scenarios.

Table 1: Albedo of roofs and pavements of the reference case and variants

Scenario	Road/Pavement Albedo	Roof Albedo
Reference	0.15	0.2
V1	0.3	0.4
V2	0.4	0.6
V3	0.5	0.8

2.3 The reference building and the night ventilation strategy

The building used for this study is part of the set of reference buildings used in Italy for the studies related to the implementation of the European Energy Performance of Buildings Directive. It was selected because its geometrical features are often found in Rome for buildings of different periods, from Middle Age until nowadays. The building has three identical floors, each of them with two flats of the same size, as inferred from Figure 1. Each apartment has 89m^2 net floor area and 242m^3 volume, the net floor height is 2.7m. The windows area is 17m^2, accounting to about 20% of the apartment surface, and they are distributed across the three different orientations for each apartment, but with limited apertures on the north façade, according to the prevalent national design criteria.

Table 2: Main thermi-physical properties of the building envelope components

Envelope component	U [W/m^{2}K]	HT [kJ/K]
Vertical wall	0.29	330
Roof	0.26	221
Ground floor	0.29	635
Window	1.85	---

Despite the majority of residential building in the consolidated urban area is still not thermally insulated, the study focuses on new and energy renovated buildings, in order to explore the performance that can be expected in the near future according to the forthcoming energy requirements. The main thermo-physical parameters (thermal transmittance U and heat capacity HT) are reported in Table 2.

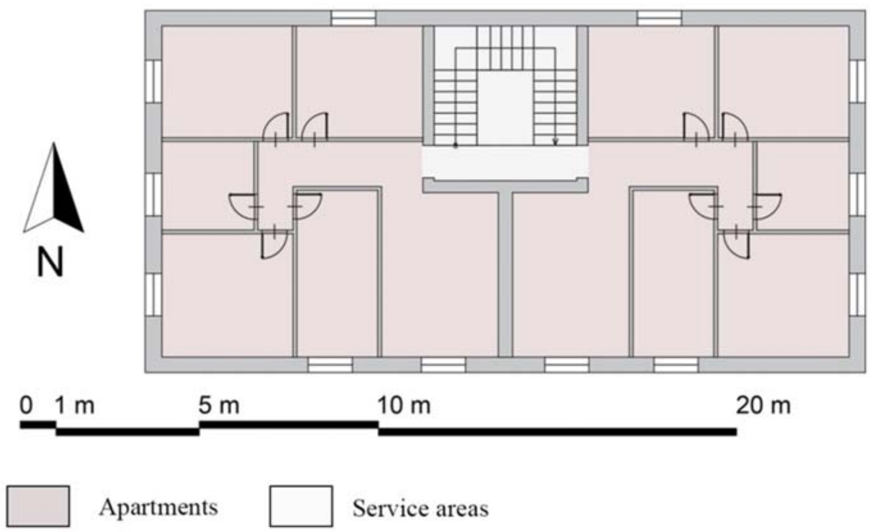

Figure 1: Reference building floor-plan

Other relevant characteristics of the reference building were defined in accordance with the relevant requirements of the Italian building code for the assessment of the energy performance of buildings (Decreto Ministero dello Sviluppo Economico, 2015; UNI, 2014). In particular, the following settings are defined for the thermal model of the building:

- internal sensible heat gains (occupancy, lighting and appliances) 5 W/m^2;
- internal latent heat gains (occupancy and appliances) 2.5 W/m^2;
- g-value 0.60 for low-e double glazing unit of the insulated configuration;
- the external solar protection - 0.7 shading coefficient – is activated during daytime.

Concerning the natural ventilation strategies, the approach is to limit the air exchange per hour (ACH) do 0.5 h^{-1} during daytime hours (08:00-20:00) and increase the natural ventilation rate during night-time hours (20:00-08:00 of the next morning). For the night ventilation fixed values are selected for the calculation: 1, 2, 3 and 5.

2.4 The observation period and the performance indicator

The analysis was carried out for July and August 2020, period that accounts for about two third of the cooling energy use in Rome. Numerical output of the reference case for temperature at 2 meters height and wind speed at 10 meters height is used for the validation of the model. The dataset from the meso-scale simulations to be supplied to the building model includes hourly values of: air temperature and relative humidity at 2 meters height, wind speed at 10 meters height, global horizontal solar irradiation.

The thermal comfort in thermal free floating is assessed using the operative temperature as main performance indicator. This indicator is defined as the arithmetic mean of the air and mean radiant temperature for compact thermal zones (calculated starting from the temperature surfaces of the thermal zone), as is the case of the simulated apartments.

3 CALCULATION

This section reports the main contents of the calculation exercises, referring to the meso-scale analysis and to the building thermal assessment.

3.1 The meso-scale atmospheric calculation

The Weather Research and Forecasting (WRF) model is a state-of-the-art mesoscale numerical weather prediction system suitable for multiple applications, both research and operational (Skamarock et al., 2019). Its operation is based on the integration of Euler equations on a three-dimensional calculation grid, defined by the user from different points of view, such as geographical coverage, horizontal and vertical spatial resolution. In this application, the urban area of Rome is simulated at 500 m through a two-way nesting technique with a total of four nested domains with a growing spatial horizontal resolution starting from 13.5 km (Figure 2a). The vertical resolution, increasing from the bottom to the top of the domain, is approximately 12 m near the ground. Grid cells land use is categorized according to the MODIS database and urban cells are further classified in terms of morphology according to the Local Climate Zones (Stewart and Oke, 2012) based on the WUDAPT database (Ching et al., 2018; Demuzere et al., 2022). Figure 2b shows the non-urban areas and the LCZs present in Rome according to these datasets. The physical setup is based on the revised MM5 surface layer scheme, the Noah Land Surface Model, the Bougeault-Lacarrère Planetary Boundary Layer scheme coupled with the Building Effect Parameterization scheme, the Single-Moment 6-class microphysics scheme, the RRTM and the Dudhia schemes for long and short wave respectively (Skamarock et al., 2019). Initial and boundary conditions are the final operational global analysis data of the National Center for Environmental Prediction (0.25°× 0.25°, every 6 hours) (NCEP, 2015).

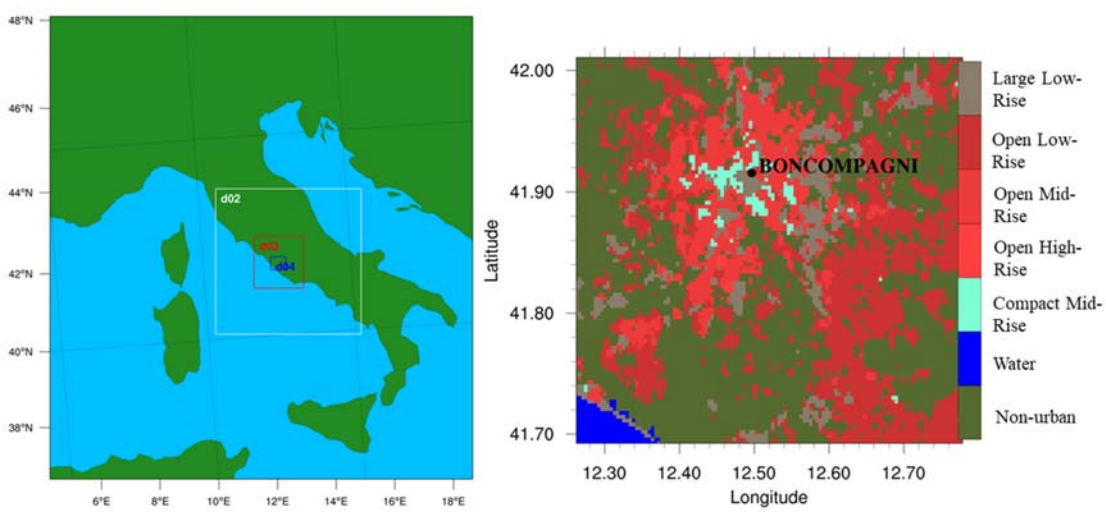

Figure 2: Geographical areas covered by the WRF nested domains (left); non-urban land use and Local Climate Zones in the domain over Rome (right). The black dot identifies the Boncompagni ARPA station whose weather records are compared with the WRF results.

3.2 The building thermal calculation

TRNSYS 17, a spread and validated model for thermal analyses in transient regime, was used for the building performance analysis. The model work as different routines properly linked each other, and each with a specific calculation task. Each TRNSYS 17 project consists of several routines linked together, each with a specific calculation task. The project implemented

for this analysis include: a) the data reader for Generic Data Files, where the outdoor air temperature, relative humidity and velocity are inputted; b) the radiation processor to calculate the solar irradiation at every incidence angle, starting from the inputted global horizontal irradiation; c) the psychometrics routine to calculate moist air properties; d) the effective sky temperature to calculate the long-wave radiation exchange, v) the Multi-Zone building model; e) the slab on grade, to model the heat transfer to soil below the building.
The simulation is run for the 62 days of July and August on hourly basis. The output is the air, mean radiant and operative temperature in each apartment. Next section report and discuss the results of the average of the operative temperature calculated in the six apartments, for the sake of brevity and because the results do not significantly the various flats.

4 RESULTS

4.1 The meso-scale calculation results

Two-months long WRF simulations have been performed for the four cases described in Table 1. In order to evaluate the performances of the WRF configuration applied here, hourly time series of temperature at 2 meters height and wind speed at 10 meters height of the reference case have been estrapolated corresponding to the Boncompagni site of the ARPA (Italian acronym for Regional Agency for Environmental Protection) Lazio and then compared to the records acquired by the ARPA Lazio weather station (Figure 3). WRF performances are quantified throght some common statistical parameters (i.e., bias, Pearson correlation coefficient, Root Mean Square Error) whose values show a very good reliability of the model (Table 3), slightly lower for the wind speed consistently with a well known feature of WRF (Ribeiro et al., 2021). The comparison of wind prfiles confirm the worse ability of WRF to simulate wind as a a well-known limitation of the model. This is due to a greater sensitivity of the wind to parameterizations of turbulent exchanges that occur in the atmospheric boundary layer and which cannot be resolved explicitly.

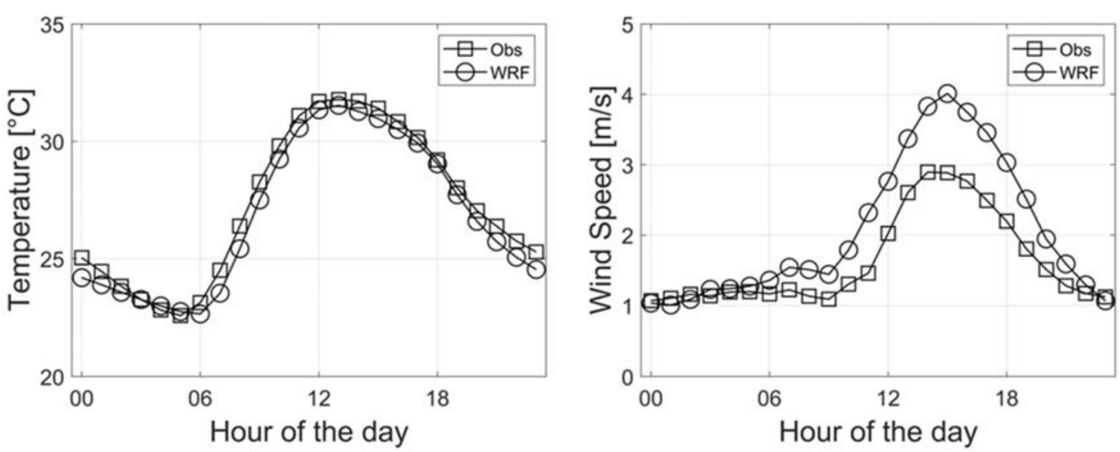

Figure 3: Comparison between average daily cycles of observations and numerical results of the reference case for air temperature (left) and wind speed (right) at the Boncompagni ARPA site.

Table 4 reports, as exemplary case, the maximum, average and minimum air temperature values calculated for the four scenarios. It can be noted that the albedo has a relevant impact on the maximum temperature, dropping by 1.7°C from the reference to the third scenario; conversely, the impact on the minimum values is limited to ±0.2°C. The average values show a progressive reduction of 0.2°C for all the modified albedo scenarios, peaking 0.6°C for the third variant.

Finally, Figure 4 shows the hourly profiles, averaged for the monitoring period and referring to the current configuration and the identified scenarios.

Table 3: Statistical parameters used for validation of WRF in this study

Statistical Parameter	Air Temperature [°C]	Wind Speed [m/s]
Bias	-0.52	0.43
Correlation coefficient	0.94	0.79
Root Mean Square Error	1.22	0.95

Table 4: Air temperature results for the different configuration

Scenario	T max [°C]	T average [°C]	Tmin [°C]
Reference	35.4	26.2	18.4
V1	34.9	26.0	18.6
V2	34.4	25.8	18.4
V3	33.7	25.6	18.2

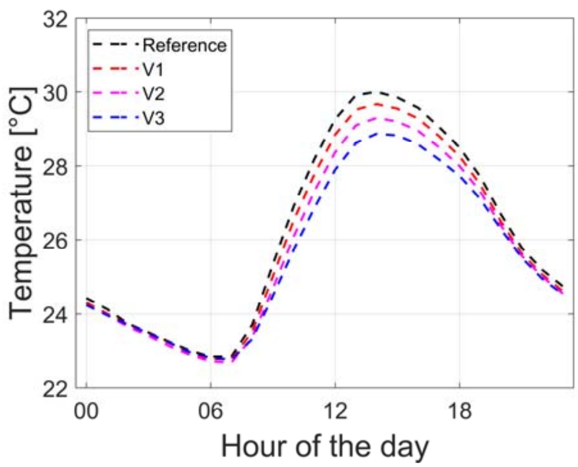

Figure 4: Hourly profiles of the air temperature, averaged for the monitoring period. Plots report the reference case and the three selected variants

4.2 The thermal comfort results

Relevant results of the simulation set are reported in Table 5. They include the maximum, average and minimum operative temperature for each scenario. The results include the number of hours above some relevant treshold values (28, 29, and 30°C); they were included as the discomfort hours calculated according to the relevant standard for adaptive comfort (last column) resulted to be quite low (CEN, 2007). Observing the absolute values of the operative temperature for the same ACH, it is noted that the variation of albedo has a low impact, with temperature reductions not greater than 0.3°C. In addition, in some cases, the minimum temperatures slightly increase in a modified albedo case with respect to the reference (see the variant 3 case). More impactufl is the increase of the ventilation rate, as the average temperature drop is 0.9-1.0°C and 1.5°C for 3 and 5 ACH respectively.

Changes are also scarcely relevant taking into account the unmet comfort hours, which peak 68 (corresponding to 5% of the total hours of the calculation period) in the reference case with the lowest night ventilation rate. Increasing the night ventilation to 2 ACH, still a quite low value,

the unmet hours account for 2% of the period in the reference case and 1% in all the albedo variants configurations.
The results change if the number of hours exceeding some reference threshold values are observed. In the reference case 28, 29, and 30°C are reached in 74, 36, and 9% hours of the period. Taking the 29°C as reference, it is observed that the occurrence is practically the same for the albedo variant 1 but it drops to 28 and 24% for the scenarios 2 and 3 respectively. The impact of the first albedo variant is confirmed also for the other ventilation rates; the albedo variant 2 shows a noticeable improvement with respect to the reference case, while the further increase of the urban albedo does not provide significant advancement in terms of temperature drops.

Table 5: Albedo of roofs and pavements of the reference case and variants

Weather	NACH [h^{-1}]	T max [°C]	T av [°C]	T min [°C]	T>28°C [h]	T>29°C [h]	>30°C [h]	Unmet h. [h]
Reference	1	31.4	28.6	25.2	1104	541	139	68
Reference	2	31.0	28.1	24.4	832	277	51	29
Reference	3	30.6	27.7	23.9	593	163	27	10
Reference	5	30.1	27.1	23.0	326	71	3	0
V1	1	31.3	28.6	25.6	1077	514	130	60
V1	2	30.9	28.1	24.9	812	267	40	21
V1	3	30.5	27.7	24.3	590	164	23	5
V1	5	30.0	27.1	23.6	327	74	2	0
V2	1	31.3	28.4	25.1	1003	412	92	48
V2	2	30.8	27.9	24.4	716	203	36	18
V2	3	30.5	27.5	23.8	504	124	17	2
V2	5	30.0	26.9	23.0	252	49	1	0
V2	1	31.2	28.4	25.3	957	360	86	45
V2	2	30.7	27.8	24.6	660	196	35	17
V3	3	30.4	27.4	24.1	441	119	17	2
V3	5	29.9	26.9	23.3	225	47	0	0

It is thus interesting to compare the reference case and the variant 2 in more detail. The effect of the modified albedo is to reduce very high indoor temperatures (above 30°C) by 34%, as the hours drop from 139 to 92; this result is relevant as the occurrence of such peak values is 9% of the all period. The operative temperature is higher than 28°C in many hours of the period, whatever the night ventilation rate might be; the effect of the albedo is here a reduction of such hours in the range between 14% (2 ACH) and 23% (5 ACH). Also noticeable is reduction for temperature above 29°C, which happens in few hundreds of hours in the reference case; in fact, it is in the 24-27% range for air exchange between 1 and $3h^{-1}$.

5 CONCLUSIONS

This study aimed at demonstrating the impact of the urban modified albedo to enhance thermal comfort conditions in residential building in the city of Rome, Italy. Meso-scale simulation showed the positive impact on the reduction of maximum and average air temperature: 1.5° and 0.6°C, respectively. The results were used to feed a dynamic building model to calculate the impact on the indoor heat mitigation and thermal comfort for different night ventilation strategies.
It was observed that the impact on average operative temperature and discomfort hours according to the relevant standard procedure was quite limited. Observing the occurrence of high temperature values (>28°C), it was instead found that the impact of the modified albedo can be relevant (reduction of hours >24%) for equivalent ACH values. In general, the impact of the night ventilation is predominant in mitigating the indoor environment; however, it must be reminded that high ventilation rates cannot be easily achieved in densely built areas in

buildings without mechanical ventilation, as it is the case for Rome and the majority of dwellings in Italy.
Next steps will explore this issue, approaching the natural ventilation also according to prevailing micro-climatic conditions; in addition, the study demonstrates the need of more accurate analyses on the discomfort hours calculated according to the existing standard, especially during extended hot periods, as they happen in the European Mediterranean region. In fact, internal studies in office buildings showed that air temperature values above 28°C are not tolerated by the vast majority of people, which appears in contrast with the adaptive method of the above cited standard.

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7 REFERENCES

Akbari, H., et al. (2015). Local climate change and urban heat island mitigation techniques – the state of the art. *Journal of Civil Engineering and Management*, 22.

CEN (2007) EN 15251:2008 - Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics.

Ching, J., Mills, G., Bechtel, B., See, L., Feddema, J., Wang, X., Ren, C., Brousse, O., Martilli, A., Neophytou, M., Mouzourides, P., Stewart, I., Hanna, A., Ng, E., Foley, M., Alexander, P., Aliaga, D., Niyogi, D., Shreevastava, A., Theeuwes, N. (2018). Wudapt: An urban weather, climate, and environmental modeling infrastructure for the anthropocene. *Bulletin of the American Meteorological Society*, 99(9), 1907–1924. https://doi.org/10.1175/BAMS-D-16-0236.1

Demuzere, M., Argüeso, D., Zonato, A., & Kittner, J. (2022). W2w: A python package that injects wudapt's local climate zone information in wrf. *Journal of Open Source Software*, 7(76), 4432. https://doi.org/10.21105/joss.04432

Falasca, S., Ciancio, V., Salata, F., Golasi, I., Rosso, F., & Curci, G. (2019). High albedo materials to counteract heat waves in cities: An assessment of meteorology, buildings energy needs and pedestrian thermal comfort. *Building and Environment*, 163.

Falasca, S., Moroni, M. and A. Cenedese, (2013). Laboratory simulations of an urban heat island in a stratified atmospheric boundary layer. *Journal of Visualization*, 16.

Falasca, S., Siani, A.M., Agnoli, S., Zinzi, M. (2024) Impact of the urban modified albedo on the energy performance of buildings. The case of Rome, Italy. Oral presentation accepted at *The 37th PLEA Conference - (Re)thinking resilience*, 25-28 June 2024, Wroclaw, Poland.

Ministero dello Sviluppo Economico (2015) Decreto del 26 giugno 2015. Applicazione delle metodologie di calcolo delle prestazioni energetiche e definizione delle prescrizioni e dei requisiti minimi degli edifici.

National Centers For Environmental Prediction/National Weather Service/NOAA/U.S. Department Of Commerce. (2015). Ncep gdas/fnl 0.25 degree global tropospheric analyses and forecast grids [dataset]. https://doi.org/10.5065/D65Q4T4Z

Oke, T.R., Johnson, G.T., Steyn, D.G. and I.D. Watson, (1991). Simulation of Surface Urban Heat Islands under 'Ideal' Conditions at Night - Part 2: Diagnosis and Causation, *Boundary Layer Meteorology*, 56.

Perkins, E. S., (2015). A review on the scientific understanding of heatwaves—Their measurement, driving mechanisms, and changes at the global scale, *Atmospheric Research*, Volumes 164–165, 2015, Pages 242-267.

Ribeiro, I., Martilli, A., Falls, M., Zonato, A., Villalba, G., 2021. Highly resolved WRF-BEP/BEM simulations over Barcelona urban area with LCZ. *Atmospheric Research* 248, 105220. https://doi.org/10.1016/j.atmosres.2020.105220

Santamouris, M., Ding, L., Fiorito, F., Oldfield, P., Osmond, P., Paolini, R., Prasad, D., & Synnefa, A. (2017). Passive and active cooling for the outdoor built environment – Analysis and assessment of the cooling potential of mitigation technologies using performance data from 220 large scale projects. *Solar Energy*, 154.

Skamarock, W. C., Klemp, J. B., Dudhia, J., Gill, D. O., Liu, Z., Berner, J., Wang, W., Powers, J. G., Duda, M. G., Barker, D. M., & Huang, X.-Y. (2019). A description of the advanced research wrf model version 4. UCAR/NCAR. https://doi.org/10.5065/1DFH-6P97

Stewart, I. D., & Oke, T. R. (2012). Local climate zones for urban temperature studies. *Bulletin of the American Meteorological Society*, 93(12), 1879–1900. https://doi.org/10.1175/BAMS-D-11-00019.1

Testa, J., and M. Krarti, (2017). A review of benefits and limitations of static and switchable cool roof systems. *Renewable and Sustainable Energy Reviews*, 77.

UNI (2011) UNI/TS 11300-1:2014 - Prestazioni energetiche degli edifici - Parte 1: Determinazione del fabbisogno di energia termica dell'edificio per la climatizzazione estiva ed invernale.

Zinzi, M., Carnielo, E., Mattoni, B. (2018) On the relation between urban climate and energy performance of buildings. A three-years experience in Rome, Italy. *Applied Energy*, Volume 221, 2018, Pages 148-160.