Present and future potential of natural night ventilation in nZEBs

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Abstract. The increase in the energy need for cooling is one of the major challenges in nearly Zero Energy Buildings. Recent constructions are characterized by high thermal insulation levels, which can be effective in preventing summer discomfort in combination with accurate control of solar gains through glazed surfaces and discharge of overall gains via ventilation. In addition, urbanization, densification and the global warming trends registered in the last decades can increase the risk and magnitude of overheating effect if an accurate design and use of correct technologies and good practices are not considered. The paper investigates the effects and the potential of natural night ventilation, as a strategy to reduce the energy need for cooling even taking into account the evolution of surrounding urban area with the exacerbation of urban heat island under future weather projections. Among the different tools available for the assessment of the cooling potential in buildings, the research focuses on two methodologies, which are adaptable to the conceptual design phase, where a first approximation of the natural ventilation potential is required. The study is developed on the weather datasets referred to the area of Milan and shows the future evolution of the night cooling potential, highlighting the importance of orienting building design towards greater integration between different passive cooling strategies for the summer period.

Table 1. List of acronyms used in the paper.

Acronyms	Meaning
NV	Natural Ventilation
CCP	Climatic Cooling Potential
CPNV	Climatic Potential for Natural Ventilation
IPCC	Intergovernmental Panel for Climate Change
GCM	Global Climate Model
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers

1. Introduction

Heating, ventilation, and air-conditioning (HVAC) is the largest energy end-use both in the residential and non-residential sector [1][2] and due to the temperature rise at a global scale and the heat island effect, energy needs for cooling during summer are expected to grow significantly. Buildings, especially non-residential ones, increasingly include air conditioning systems or hybrid solutions and this has entailed growing costs in energy use and mechanical systems.

Directive 2010/31/EU states that "Recent years have seen a rise in the number of air-conditioning systems in European countries. This creates considerable problems at peak load times, increasing the cost of electricity and disrupting the energy balance. Priority should be given to strategies which enhance the thermal performance of buildings during the summer period. To that end, there should be a focus on measures which avoid overheating, such as shading and sufficient thermal capacity in the building construction, and further development and application of passive cooling techniques, primarily those that improve indoor climatic conditions and the microclimate around buildings".

As suggested by the directive, the implementation of passive cooling strategies, since the very beginning of the project, can lead to considerable energy and costs reductions. Several studies [3][4] analyse the available passive cooling techniques such as solar and heat protection measures, heat modulation and heat dissipation techniques. Among them, natural ventilation (NV) is a very old and well-known strategy to guarantee thermal comfort and indoor air quality and it is considered one of the most effective passive techniques to be adopted also in nearly Zero Energy Buildings (nZEBs) also to reduce the energy need for cooling. However, NV is strongly affected by outdoor temperature: in particular, focusing on night ventilation, the higher the temperature difference between indoor and outdoor during the night, the greater will be the potential to cool down the structures during those hours, allowing the building to act as a heat sink for the following day. Therefore, it is important to contextualize NV in relation to the specific climate where it is applied. Furthermore, taking into account the issue of global warming, not only the effectiveness of the NV in the present must be assessed, but also, and most importantly, its resiliency in the long-term must be taken into account. The average temperature of our planet is indeed increasing rapidly. According to the analysis performed by NASA and the National Oceanic and Atmospheric Administration (NOAA), Earth's global surface temperatures in 2018 were the fourth warmest since 1880 and the year 2015 was the warmest on record (since 1880) [5]. This trend is expected to continue over the long term [6]. According to the fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC), the average air temperature during the period 2081-2100 is expected to be 0.3-4.8 °C higher than that during the 1986-2005 period [7]. Analyzing the climatic variations, ongoing and future, is the fundamental premise for the impact assessment and for the adaptation strategy to climate change. The evaluation of the present and past climate and of the variations underway is based on the observation of climate variables and on the application of statistical methods and models of recognition and estimation of current trends. On the other hand, the estimation of the future climate is based on the projections provided by global climate models (GCM). According to the definition of the World Meteorological Organization (WMO), climate projections provide the description of the climate changes that may occur in the coming decades, in relation to various possible evolutions of global socio-economic development, technological change, energy and land use. The working groups of the IPCC have developed scenarios for both contaminant emissions and global warming; these scenarios are able to describe the likely average global conditions in the future. To evaluate the present and future potential of natural ventilation, the paper presents a study on different weather datasets from 1960 to 2080 using two preliminary tools, whose use is recommended in the conceptual design phase of the building. In addition, the analysis is focused on the choice of two different locations: one in the city and another in the peri-urban area, in order to show the effect of the urban heat island.

2. Comparison of different weather datasets

The weather files used in this study have been extracted from the meteorological database Meteonorm and are related to the area of Milan, distinguished between the location of Milan-City (urban area) and Milan-Linate (peri-urban area). In this study, we used the Meteonorm version 7.3 to generate the typical weather file and four future weather files for the years 2020, 2030, 2050 and 2080 (Figure 1). The datasets include hourly values of different parameters such as dry-bulb temperature, dew-point temperature, relative humidity, atmospheric pressure, wind direction and speed, global and diffuse horizontal radiation, direct normal radiation, total sky cover, etc. For the objectives of this research, only hourly values of dry bulb temperature (DBT) and relative humidity (RH) have been used.

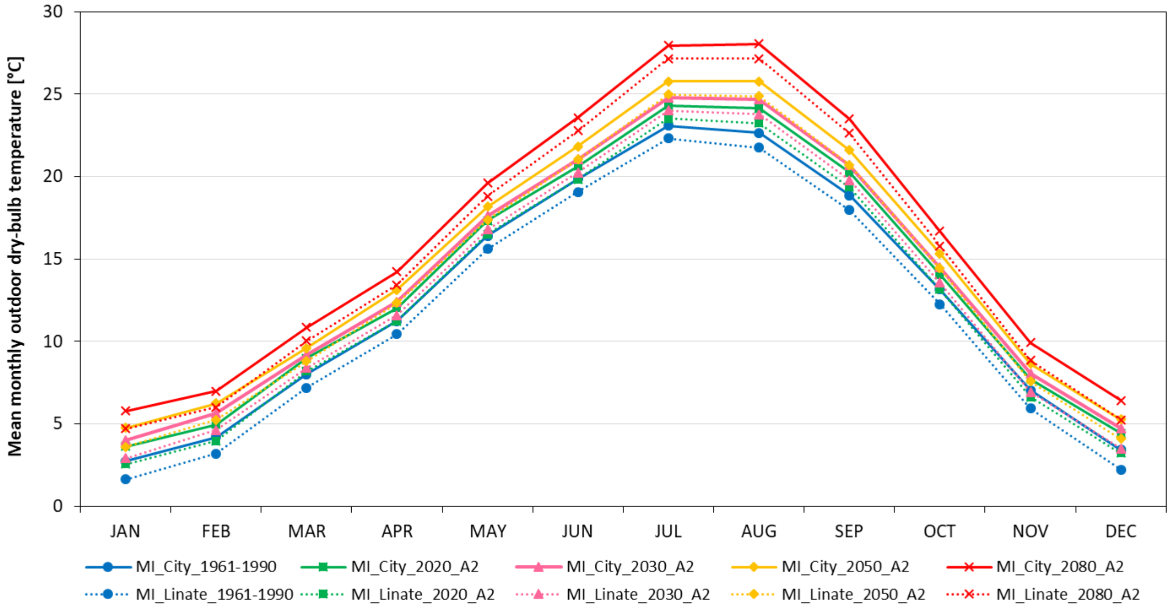

Figure 1. Average monthly temperature in Milan-City (solid line) and Milan-Linate (dotted line) comparing the weather file based on the period 1961-1990 (blue) and the four weather projections in 2020 (green), 2030 (pink), 2050 (yellow), 2080 (red), choosing scenario A2.

The global climatological database Meteonorm [8] is widely used as meteorological input for simulation of solar applications and buildings. It's a combination of a climate database, a spatial interpolation tool and a stochastic weather generator [9]. To meet today needs, monthly average data is no longer sufficient, and many design codes call for hourly or minute data. However, since the interpolation of hourly values at arbitrary locations is extremely time-consuming (only feasible using satellite data), and necessitates extensive storage capacity, only interpolated monthly values at nodal points are stored. In order to generate hourly values at any desired location, stochastic models are used. The stochastic models generate intermediate data having the same statistical properties as the measured data, i.e. average value, variance, and characteristic sequence (autocorrelation). The generated data approximates the natural characteristics as far as possible. Data generated in this way can be used satisfactorily in place of long-term measured data [10]. Starting with the monthly global radiation values from the Global Energy Balance Archive [11], first the daily values, then the hourly and minute values of radiation are generated stochastically. Further characteristic values, e.g. temperature, humidity, wind, longwave radiation, are derived from these as required, conjoining meteorological input parameters from databases of WMO and Nation Climatic Data Center (NCDC) (periods 1961-90 and 1996-2005) with the generated global radiation time series, as daily temperature variations and solar radiation are inter-linked.

This tool can also be used for climate change studies, using as input the results of GCMs under the IPCC Fourth Assessment Report (AR4) [12], instead of climate data stored in typical weather files. From all the 18 public global climate models [13], an average has been made at a spatial resolution of 1° [14]. The anomalies of the parameters temperature, precipitation and global radiation and the three scenarios B1 (low), A1B (mid) and A2 (high) have been included [15]. The A2 scenarios are of a more divided world. The A2 family of scenarios is characterized by a world of independently operating, self-reliant nations and continuously increasing population. The B1 scenarios are of a world more integrated, and more ecologically friendly. The A1B scenarios are of a more integrated world; a balanced emphasis on all energy sources. With the combination of Meteonorm's database 1961-90, the interpolation algorithms and the stochastic generation, future weather files can be calculated for any site, for three different scenarios (B1, A1B and A2) and for 10-year bins between 2010 and 2100 [14]. In the following analyses, only the most critical scenario (A2) will be presented since it is one of the most widely used combinations in climate predictions [16]. In terms of overall forcing, the A2 scenario from AR4 is broadly comparable to the RCP8.5 scenario from AR5 [7].

Meteonorm can, therefore, be used as a relatively simple method to enhance the spatial and temporal resolution instead of using complicated and time consuming downscaling methods based on regional climate models [14]. The Meteonorm software has been used in this last decade in several studies for forecasting outdoor climate [17]-[26].

3. Methodology to evaluate the cooling potential

To evaluate the potential of natural ventilation in buildings, different tools are available depending on the design phase when they are applied [27]. The research focuses on the conceptual design phase through the application of two simplified methodologies for the calculation of the CPNV and CPP indexes. Both of them are preliminary evaluation methods to estimate the potential for passive cooling of buildings by natural ventilation just analysing climatic data, without considering any building-specific parameter.

The first tool used for the analysis is based on the calculation of the index CPNV (Climatic Potential for Natural Ventilation) defined as the number of hours in a year when natural ventilation could be performed, divided by the total number of hours in a year [27]:

$$\text{CPNV} = \frac{\sum_{i=1}^{n} h_{NV,i}}{h_{tot}} \tag{1}$$

where $h_{NV,i}$ is the i-th hour when natural ventilation is possible and h_{tot} is the total number of hours in a year. The method analyses a yearly weather dataset and sets constraints for indoor temperature and humidity ratio. The CPNV is calculated as the number of hours during which the outdoor air temperature (t_{out}) and the outdoor humidity ratio (X_{out}) are within the following comfort ranges:

$$t_{in,l} \leq t_{out} \leq t_{in,u} \text{ and } X_{in,l} \leq X_{out} \leq X_{in,u}, \tag{2}$$

where t is the temperature and X is the humidity ratio; subscripts *in*, *out*, *l*, and *u* stand for *indoor*, *outdoor*, *lower* and *upper*, respectively. The comfort temperatures thresholds are defined according to the ASHRAE Standard 55-2017 [28] as a function of the prevailing mean outdoor air temperature $t_{pma(out)}$, which is based on the arithmetic average of the mean daily outdoor temperatures $t_{mda(out)}$ of a number of sequential days between seven and 30, prior to the day in question. In the following analyses a number of seven has been chosen and $t_{mda(out)}$ is calculated as the arithmetic mean for a 24-hour period. The upper limit for the indoor temperature ($t_{in,u}$) in the CPNV calculation is set as equal to the acceptable operative temperature defined in the ASHRAE procedure, choosing the 80 % of satisfied occupants:

$$t_{in,u} = t_{comf} + 3.5 \tag{3}$$

where $t_{comf} = 17.8 + 0.31 \cdot t_{pma(out)}$

The lower limit $t_{in,l}$ is chosen equal to 12 °C, as suggested in literature when natural ventilation is used for cooling purposes [29].

The humidity ratios thresholds $X_{in,u}$ and $X_{in,l}$ are calculated as a function of the two temperatures, $t_{in,u}$ and $t_{in,l}$, and 70 % RH and 30 % RH respectively, as follows [30]:

$$X = 0.621945 \cdot \frac{p_{ws} \cdot RH}{p - (p_{ws} \cdot RH)} \quad \left[\frac{kg_v}{kg_{da}}\right] \tag{4}$$

where p is the atmospheric pressure and p_{ws} is the partial pressure of vapour under saturation conditions at the chosen temperature.

These thresholds can identify further eight different sets, as reported in Table 2, which are representative of various conditions in which natural ventilation cannot be exploited.

Table 2. Temperature and humidity ratio thresholds which characterise the nine areas in terms of suitability to natural ventilation.

		t_{out} [°C]	X_{out} [kg_v/kg_{da}]
9	**Cold and humid**	$t_{out,9} < t_{in,l}$	$X_{out,9} > X_{in,u}$
8	**Cold**	$t_{out,8} < t_{in,l}$	$X_{in,l} \leq X_{out,8} \leq X_{in,u}$
7	**Cold and dry**	$t_{out,7} < t_{in,l}$	$X_{out,7} < X_{in,l}$
6	**Humid**	$t_{in,l} \leq t_{out,6} \leq t_{in,u}$	$X_{out,6} > X_{in,u}$
5	**Optimum (CPNV)**	$t_{in,l} \leq t_{out,5} \leq t_{in,u}$	$X_{in,l} \leq X_{out,5} \leq X_{in,u}$
4	**Dry**	$t_{in,l} \leq t_{out,4} \leq t_{in,u}$	$X_{out,4} < X_{in,l}$
3	**Hot and humid**	$t_{out,3} > t_{in,u}$	$X_{out,3} > X_{in,u}$
2	**Hot**	$t_{out,2} > t_{in,u}$	$X_{in,l} \leq X_{out,2} \leq X_{in,u}$
1	**Hot and dry**	$t_{out,1} > t_{in,u}$	$X_{out,1} < X_{in,l}$

The second tool calculates the average daily climatic cooling potential (CCP) for night natural ventilation over a certain period (e.g. 1 month), as the sum of the degree-hours between the indoor building temperature T_B and the outdoor dry-bulb air temperature T_E [31], divided by the considered number of nights, N.

$$\text{CCP} = \frac{1}{N}\sum_{n=1}^{N}\sum_{h=\overline{h}_I}^{\overline{h}_F} m_{n,h}\,(T_{B,n,h} - T_{E,n,h}) \qquad \begin{cases} m = 1\ [h] & if\ T_B - T_E \geq \Delta T_{crit} \\ m = 0\ [h] & if\ T_B - T_E < \Delta T_{crit} \end{cases} \quad [K\ h/night] \quad (5)$$

where the running index h stands for the hour of the day, $\overline{h}_I$ and $\overline{h}_F$ denote the initial and the final hour of night-time ventilation, and ΔT_{crit} is the threshold value of the temperature difference, when night-time ventilation is applied. In the analysis, night-time ventilation is considered between $\overline{h}_I$ = 7 p.m. and $\overline{h}_F$ = 7 a.m. As a certain temperature-difference is needed for effective convection, night ventilation is only applied if the difference between building and ambient temperature is greater than ΔT_{crit} = 3 K. The method uses a variable building temperature for the calculation of the climatic cooling potential to take into account the fact that the temperature of the building varies when energy is stored or released. The temperature T_B in °C is assumed to oscillate harmonically:

$$T_{B,h} = 24.5 + 2.5\cos\left(2\pi\frac{h-\overline{h}_I}{24}\right) \qquad (6)$$

According to this formula, the maximum building temperature occurs at the initial hour of night-ventilation, $\overline{h}_I$, and as the considered ventilation period is 12 h, the minimum building temperature occurs at the final hour $\overline{h}_F$. The temperature range of T_B = 24.5 ± 2.5 °C follows the values recommended by the standard EN 15251 according to the PMV model for offices and spaces with similar activities, choosing category III [32].

4. Application of the methods

This section shows the results of the application of the tools for the calculation of the indexes CPNV and CCP based on hourly data following the methodologies described in section 3. The analysed set of weather files have been presented in section 2 and are representatives of an urban centre (Milan-City) and a peri-urban area (Milan-Linate).

4.1 Climatic potential for natural ventilation: CPNV tool

Figure 2 and Table 3 contrast the monthly values of CPNV index, divided in night-CPNV and day-CPNV, under 1961-1990 weather dataset and 2080_A2 future projection for Milan-City and Milan-Linate. The index night-CPNV represents the fraction of hours when night-time ventilation is compatible with the assumed limits on outdoor temperature and humidity ratio and is calculated considering the hours comprised between 7 p.m. and 7 a.m., while the day-time potential is evaluated from 7 a.m. to 7 p.m. The research aims to assess the potential of night-CPNV, especially in the summer season when it is more likely to open the windows and allow the fresh air to cool down the structures. In the hottest months (July and August) the night-CPNV decreases by 30 % passing from the oldest weather dataset (1961-1990) to the furthest weather projection (2080_A2). On the other hand, it is important to note that, because of the growing temperatures, there will be a need for removing cooling load from buildings also in part of the shoulder seasons (spring and autumn) and natural ventilation would become possible in those other periods of the year and important to reduce the total need of active cooling over the year. Also for the day time CPNV the trend is similar, except for the months of May, June and September, during which the potential shows a reduction from 1961-1990 to 2080_A2. The comparison between the two locations instead, shows the urban heat island effect: both during the night and day, the CPNV decreases passing from the rural area to the city centre in the hottest months. The trend is the opposite in the rest of the months.

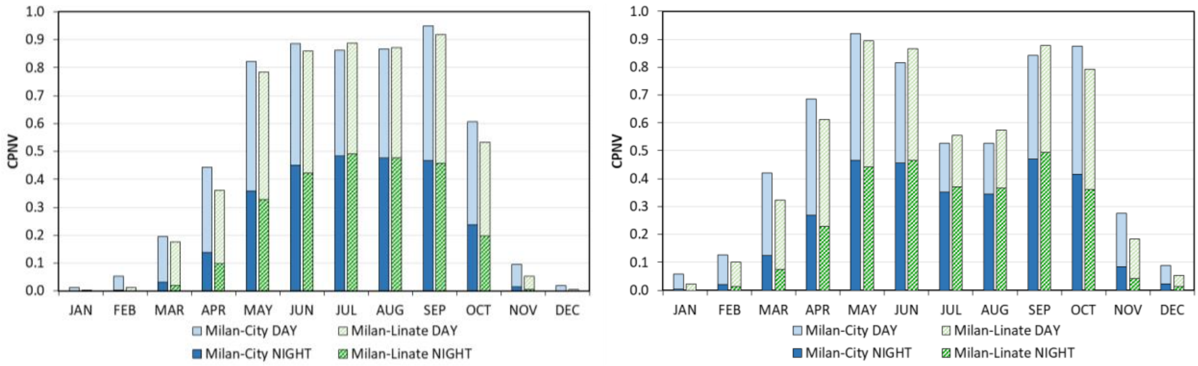

Figure 2. Comparison of monthly CPNV [-] during the night (7 p.m. - 7 a.m) and the day (7 a.m. - 7 p.m.) considering the oldest weather dataset (1961-1990) and the farthest projection (2080_A2) for Milan-City and Milan-Linate weather datasets.

Table 3. CPNV [-], night-CPNV and day-CPNV trend under 1961-1990 weather dataset and 2080_A2 future projection.

	CPNV				night-CPNV				day-CPNV			
	1961-1990		2080_A2		1961-1990		2080_A2		1961-1990		2080_A2	
	City	Linate	City	Linate	City	Linate	City	Linate	City	Linate	City	Linate
January	0.01	0.00	0.06	0.02	0.00	0.00	0.00	0.00	0.01	0.00	0.06	0.02
February	0.05	0.01	0.13	0.10	0.00	0.00	0.02	0.01	0.05	0.01	0.11	0.09
March	0.19	0.17	0.42	0.32	0.03	0.02	0.12	0.08	0.16	0.16	0.30	0.25
April	0.44	0.36	0.68	0.61	0.14	0.10	0.27	0.23	0.31	0.26	0.42	0.38
May	0.82	0.78	0.92	0.90	0.36	0.33	0.47	0.44	0.46	0.46	0.45	0.45
June	0.89	0.86	0.82	0.87	0.45	0.42	0.46	0.47	0.43	0.44	0.36	0.40
July	0.86	0.89	0.53	0.56	0.48	0.49	0.35	0.37	0.38	0.40	0.18	0.19
August	0.87	0.87	0.53	0.58	0.48	0.48	0.34	0.37	0.39	0.40	0.18	0.21
September	0.95	0.92	0.84	0.88	0.47	0.46	0.47	0.49	0.48	0.46	0.37	0.38
October	0.61	0.53	0.88	0.79	0.24	0.20	0.42	0.36	0.37	0.34	0.46	0.43
November	0.09	0.05	0.28	0.18	0.01	0.01	0.08	0.04	0.08	0.05	0.19	0.14
December	0.02	0.01	0.09	0.05	0.00	0.00	0.02	0.01	0.02	0.01	0.07	0.04
Yearly	0.49	0.46	0.52	0.49	0.22	0.21	0.25	0.24	0.26	0.25	0.26	0.25

Another effective way to show the results of the calculation of the CPNV is through the heat maps, defined in section 3, in which each square reports the average hourly weekly condition. From 1961 to 2080, they show a progressive increase in temperature in the summer season, which reduces dramatically the possibility to use natural ventilation during the day. In Figure 3, the heat map representing CPNV under 1961-1990 weather dataset shows that from May till October there is potential to exploit natural ventilation, except for some weeks in summer when the temperature is too hot. In 2080 instead, as shown in Figure 4, during the summer season is not possible to use natural ventilation during the day since the weather is too hot and sometimes hot and humid. However, during the night the cooling potential is exploitable and, as shown also in Figure 2, the CPNV increases in the mid-seasons allowing the openings of windows to allow the entrance of fresh air, if necessary.

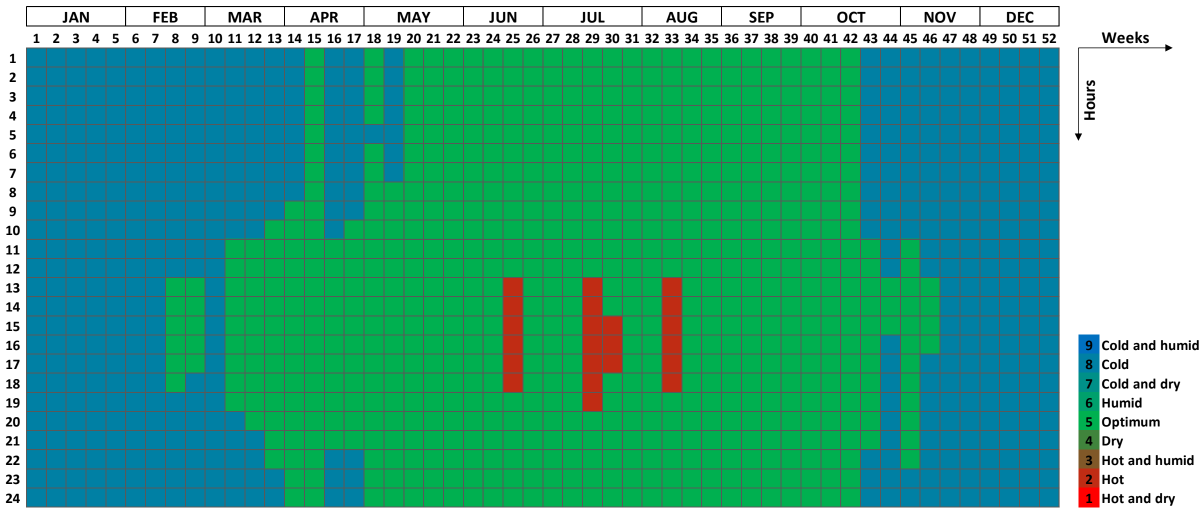

Figure 3. Heat map to evaluate CPNV during the year in Milan-City using 1961-1990 weather dataset. The x-axis represents the week number, the y-axis the hours of the day.

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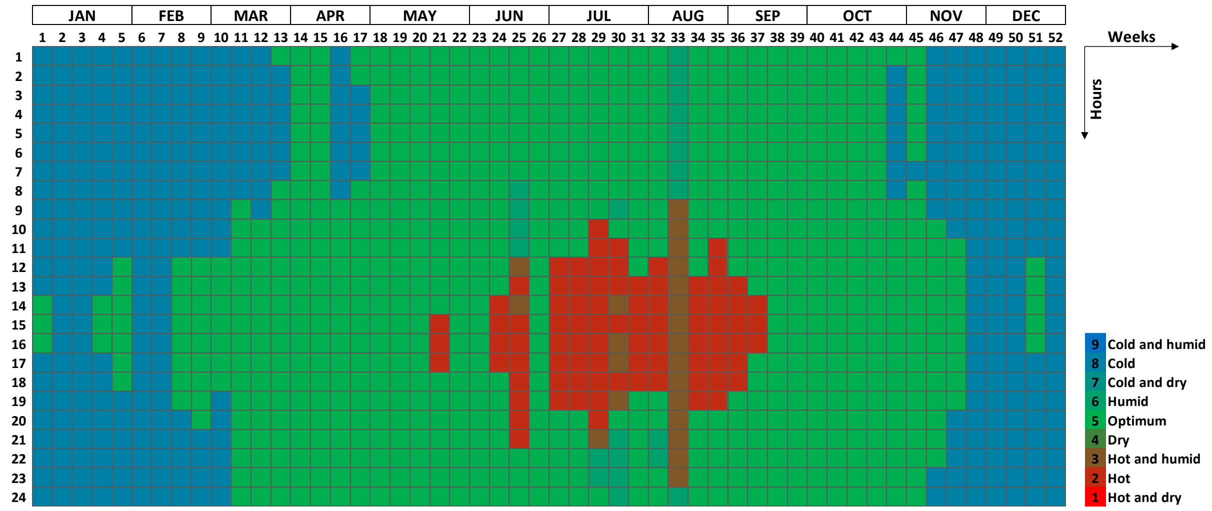

Figure 4. Heat map to evaluate CPNV along the year in Milan City using 2080 weather dataset projection. The x-axis represents the week number, the y-axis the hours of the day.

4.2 Climatic cooling potential: CCP tool

The CPNV analysis in section 4.1 has shown that in Milan the humidity does not affect significantly the cooling potential. Therefore, as a further step, the research investigates the results of the application of the CCP methodology (which considers only limits on temperature, not on humidity) to evaluate the amount of stored heat, which is possible to discharge per night by using natural ventilation. Table 4 shows the results of the calculation of the CCP index for the city of Milan and the area of Linate under the different weather datasets described in section 2, calculated for each month of the year. The night cooling potential decreases with the increase in temperature, as highlighted e.g. in Figure 5 for Milan-City. In particular, for the month of July, it is possible to observe a significant reduction in the CCP, passing from 38 [K h/night] in Milan-City and 49 in Milan-Linate during the period 1961-1990 (coolest weather dataset) to 3 and 5 respectively, in 2080 projection. The cooling potential is usually exploited mainly during the summer season, even though, considering the future trend of the weather, it can be an effective strategy in the mid-seasons. Table 4 underlines also a reduction in the CCP moving from the peri-urban area (Milan-Linate) to the city centre, which reflects the effect of the urban heat island.

Table 4. CCP [K h/night] in Milan-City and in Milan-Linate analysing different weather datasets: 1961-1990 and four future weather projections (2020-2030-2050-2080).

	1961-1990		2020_A2		2030_A2		2050_A2		2080_A2	
	City	Linate	City	Linate	City	Linate	City	Linate	City	Linate
January	275	288	265	277	260	273	251	264	238	251
February	261	274	251	263	245	256	237	249	227	239
March	221	231	210	220	207	216	202	213	188	197
April	184	193	175	184	171	179	161	170	148	158
May	125	135	114	124	110	122	105	115	86	97
June	83	92	72	82	65	77	57	66	38	47
July	38	49	26	32	20	28	13	21	3	5
August	44	57	28	38	22	29	16	20	4	7
September	91	103	73	85	70	80	57	68	35	44
October	155	166	144	156	138	150	130	140	113	123
November	224	236	216	229	211	225	204	218	189	202
December	266	279	253	268	251	265	244	258	229	243
Yearly	163	175	152	163	147	158	139	150	124	134

Figure 5 compares the trend of the building temperature T_B and outdoor air temperatures T_E in July, considering the oldest weather dataset MI_City_1961-1990 and the furthest weather projection MI_City_2080_A2. For the whole month, it is possible to observe the increase in outdoor temperatures and the consequent reduction in cooling potential. Figure 6 shows, as an example, the graphical representation of the cooling potential - the blue area comprised between the building temperature curve (upper boundary) and the outdoor air temperature (lower boundary) - highlighting the reduction in the CCP from the coldest weather dataset (left) to the warmest one (projection in 2080).

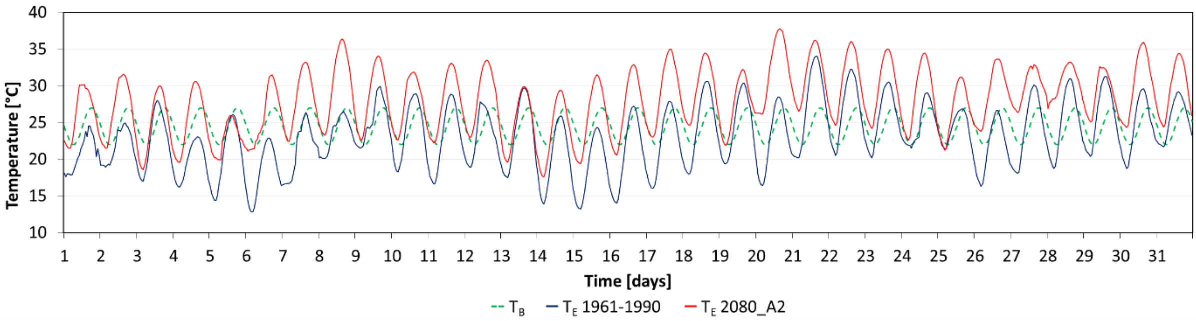

Figure 5. Comparison between the building temperature T_B (in green, dashed line) and the outdoor dry-bulb air temperatures T_E, in July, in Milan-City, considering the oldest weather dataset MI_City_1961-1990 (in blue) and the furthest weather projection MI_City_2080_A2 (in red).

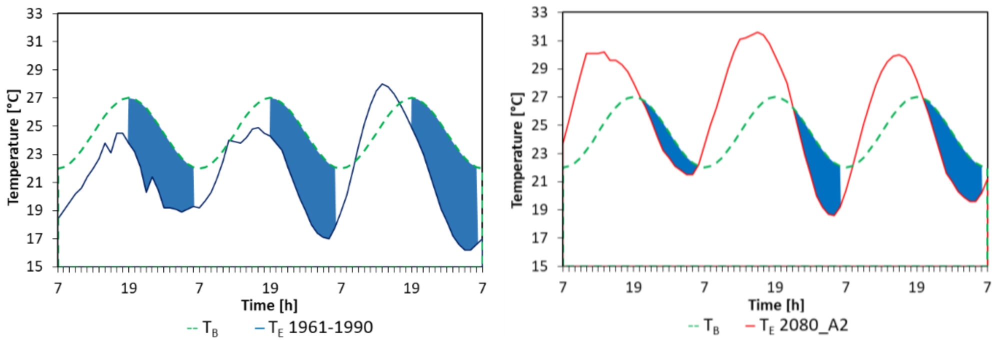

Figure 6. Comparison between the building temperature T_B (in green, dashed line) and the outdoor dry-bulb air temperatures T_E, for the first three days of July, for two weather datasets in Milan-City: 1961-1990 (left figure, blue curve) and 2080 projection (right figure, red curve). Blue areas show graphically the climatic cooling potential between 7 p.m. and 7 a.m.

5. Discussion of the results

The research analyses a two-step approach for the preliminary evaluation of the climatic cooling potential by natural ventilation. The results show the reduction in the night cooling potential in the summer season under future weather projections by using both the proposed tools; however, the CCP methodology seems to underestimate the effectiveness of this strategy respect to the use of CPNV. This is due to the building temperature assumed in the method, as proposed in [31], which is based on the limits defined by EN 15251 for comfort category III for mechanically cooled buildings, according to the PMV model. However, since the analysis is based on the application of natural ventilation in buildings, it would be preferable to base the calculations on the limits related to the adaptive comfort model. The higher indoor temperatures evaluated as comfortable in the adaptive model would allow for a higher temperature difference between indoor and outdoor, thus increasing the value of CCP. This approach may be explored in a future development of this study.

These methodologies, which precede any technological decision, do not consider any building specific parameter and are highly dependent on the climatic database used. Consequently, the accuracy of the results is strictly linked to the reliability of the weather datasets used. In this analysis, Meteonorm software has been selected since it is one of the most used meteorological databases in common practice by architects, engineers and building energy modellers and provide datasets based upon measured historical data from different weather stations. Nevertheless, the analysis of further weather datasets available in literature highlights some inconsistencies in the weather datasets, especially those related to future projections.

Figure 7 shows, as an example for the City of Milan, the comparison between the weather files described in section 2 and the dataset obtained from the Joint Research Centre (JRC) database for the center of the city (Latitude 45°47', longitude 9°19'). In this weather file, the solar radiation data used have been calculated from satellite data thanks to the Satellite Application Facility on Climate Monitoring (CM SAF) collaboration. The European Centre for Medium-Range Weather Forecasts (ECMWF) ERA-interim, a global atmospheric reanalysis from 1979, continuously updated in real time, provides all the other data. Dry-bulb temperature data have been corrected for elevation. The selection of the months for the typical year is done using the method described in the international Standard ISO 15927-4 [33]. The selection is done based on dry-bulb temperature, global horizontal radiation and relative humidity.

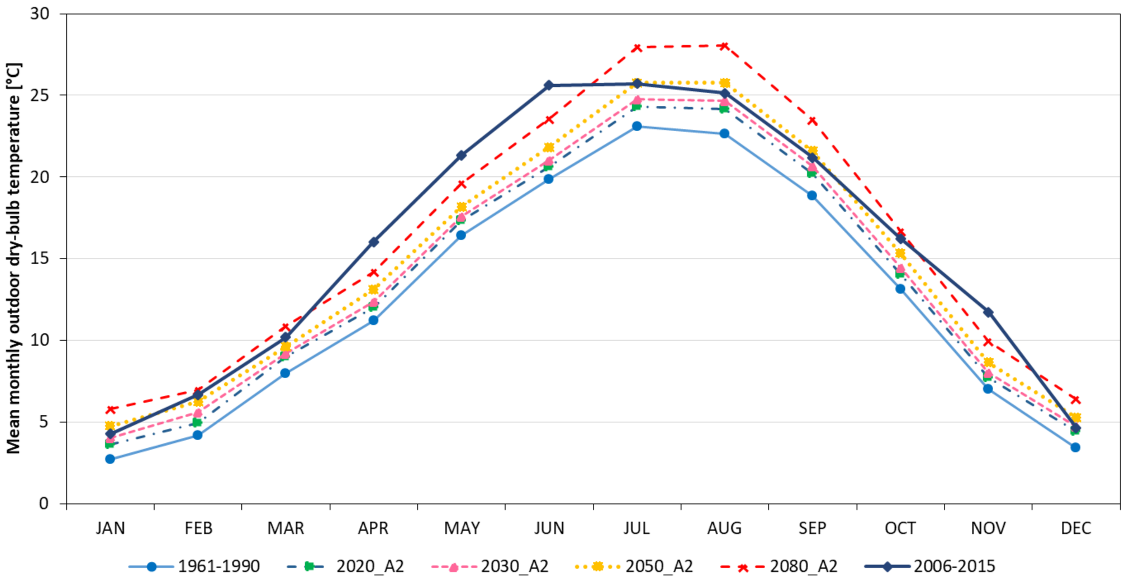

Figure 7. Comparison of average monthly temperatures in Milan-City for four future weather projections (2020_A2, 2030_A2, 2050_A2, 2080_A2) generated in Meteonorm from 1961-1990 dataset and a weather file for 2006-2015 produced by the Joint Research (JRC) Centre Database.

Future projections generated in Meteonorm from 1961-1990 dataset and plotted in Figure 7 are underestimated with respect to the trend depicted by MI_City_2006-2015 weather file of JRC, which is based on real measured data from the last decade. This suggests a further reduction in the cooling potential in the future with respect to the results obtained in section 4, due to the higher temperatures expected. A crucial research effort should hence be directed towards the creation of more reliable weather datasets and an update to the climate evolution [34] [35]. The possible underestimation of the cooling potential using Meteonorm weather projections has indeed supported the choice of presenting the worse emission scenario (A2) among those available.

The research proposes also an evaluation of the urban heat island effect based on the comparison of two locations situated nearby, one in the city centre of Milan and the other one in the surrounding rural area (Linate). The results for the historical dataset 1961-90 (Figure 2, left) show a lower cooling potential for natural ventilation in the city, compared to Linate, in July and August, both during night and day. In all the other months, the potential is greater in the city. Both these results are due to the systematically higher temperatures recorded in the city during the whole day, connected to the heat island effect (a combination of solar radiation on high-absorbing surfaces, high thermal masses, urban production of heat, obstacles to wind cooling by convection, etc.). In the hottest months, the temperatures exceed the upper limit set for the CPNV more in the city than in Linate, thus reducing for overheating the number of hours in which the natural ventilation is considered acceptable, according to this approach. On the other hand, in the milder months, the main constraint is the lower limit of outdoor temperature under which ventilation is considered inappropriate under the CPNV method. This limitation intervenes more frequently in the Linate area, thus reducing the CPNV in this location. The projections in the 2080 scenario (Figure 2, right) show a reduction in the potential for both locations during the hottest months, with an increase in the difference in the cooling potential between Linate and Milan-city. In the milder months, the potential increases in both cases, due to the general increase in temperatures, which are less likely to encounter the limitation due to the lower limit of outdoor temperature. This lower limit might be more relevant in residential buildings than in commercial/public buildings which might be unoccupied at night.

6. Conclusion

The presented research proposes an analysis of the potential of natural night ventilation under future weather climates based on preliminary evaluation methods, which can provide useful information during the conceptual design stage of a building. The location chosen is Milan. This is a general study, hence generic boundary conditions have been applied, concerning the time of activation of night natural ventilation and the lower temperature admitted. However, in case of analysis of a specific case study, more favourable boundary conditions may be applied, e.g. in the case of offices and schools, the time schedules are well defined and the starting time of natural ventilation may be anticipated (e.g. at 6 p.m. instead of 7 p.m.) and the lower boundary temperature may be lowered [27]. The preliminary evaluation of the night ventilation cooling potential through the presented methods might be useful to estimate the energy saving potential of ventilative cooling compared to the use of an active cooling system. If, on the other hand, the possibility to avoid at all the installation of an active system must be investigated, the synthetic indexes used here may not be sufficient. In this case, indeed it is necessary to evaluate the extreme temperature conditions, e.g. the hours in which natural ventilation is not able to provide cooling. Analysing the magnitude and frequency of these occurrences it may be possible to evaluate the necessity of the installation of an active cooling system as a cooling backup and to proceed to its sizing. In Milan, the results of the analyses under future weather scenario seem to imply the necessity to install active cooling, especially to cope with conditions in the hottest months. However, it must be considered that a correct and conscious building design based on a combination of adequate passive strategies such as solar protections, opaque dynamic insulation systems, efficient lighting, occupancy sensors and ceiling fans in support of natural ventilation, can contribute to significantly reduce energy needs for cooling, with consequent costs and energy savings. To this end, further studies on the measures which can avoid overheating and improvements in the reliability of the available datasets and simulation tools, are therefore strongly needed to control the performance of buildings during summer in the future design.

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