Effect of Climate Change on Building Performance: the Role of Ventilative Cooling

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Abstract

Climate Change represents a priority, due to the large variety of implications and importance that it has reached throughout the last decades. In an effort to address this global and local challenge and in order to restrict temperature rise to 2 °C over the next century, it will need to address this topic from several angles, as confirmed by the last COP meetings in Paris and in Marrakech.

In this context, the paper presents the modelling and assessment of ventilative cooling applicability in the future of the Mediteranean area under the effects of climate change. Results show that natural ventilation will continue to be of paramount importance in the Mediterranean climate but its highest effectiveness will be displaced from summer to spring and autumn.

Introduction

Climate Change represents a priority, due to the large variety of implications and importance that it has reached throughout the last decades as confirmed by COP21 climate meeting in Paris. The current global average surface temperature grew higher by 0.85 °C from 1880 to 2012, as discussed in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). This trend will continue developing in the next years and, if decisive actions are not carried out soon, the average global temperature could increase of around 5.5 °C in the long term and by almost 4 °C by the end of this century (IPCC, 2014).

The climate change will have an impact on our lives, the environment and the global economy. At the building level, the increase in air temperature could result in an increase of the building energy use. This will have consequences on our current understanding of optimal building and systems design for all zones of the world (Beccali et al., 2007; Cellura et al., 2013a, Guarino et al., 2015). Moreover, for designers and engineers understand the change in building energy demand due to global warming will be fundamental in the design and retrofit of future buildings (Cellura et al., 2015).

In this context, previous studies already analyse the effect of a warmer climate on building energy performances.

In Farrou et al. (2014) the impact of climate change on the energy performance of a hotel in Greece is investigated, according to the emission scenario developed in the Third Assessment Report of the IPCC (IPCC TAR). The assessment is performed via hourly simulations using TRNSYS (University of Wisconsin, 2012). The simulation results indicate an increase in the cooling energy demand by 34% in 2050 and 63% in 2080 if compared to today.

Waddicor et al. (2016) investigated the impact of climate change on the energy performance of a library located in Turin (Italy). The impacts of climate change on building energy consumptions for the period from 2010 to 2060 are explored using IPCC TAR's emission scenarios. Results show a decrease in the building heating energy use and an increase in the cooling energy demand. In particular, considering the worst emissions scenario, in 2060 the cooling energy demand increases by about 35% while heating energy demand decreases by about 25%.

As discussed in (IEA, 2013), due to an overall trend towards lower heating and higher cooling demands in buildings, passive cooling techniques, especially for areas with mild climates such as the Mediterranean, could become always more relevant. In particular, ventilative cooling, defined as the use of external air strategies to cool indoor spaces, could reduce the energy consumption of buildings while maintaining thermal comfort.

The ventilative cooling is a cooling technique effective in achieving low energy requirements in current (Guarino et al., 2016; Santamouris and Kolokotsa, 2013; Givoni and Hoffman, 1966) and future buildings (Artman et al., 2008). In particular, in Artman et al. (2008) the climate of eight European representative locations is studied through a method based on degree-hours. The results suggest that although cooling by night-time ventilation is expected to become increasingly ineffective during summer, it still is expected to be an effective strategy during mid-seasons.

Methods

In this context, the paper investigates the impact of climate change for two specific future time frames (2050 and 2080) on building energy performance for the city of Naples. In particular, the role of natural ventilative cooling as mean to passively cooling buildings in future climates is investigated.

An ideal building model, representative of a relevant part of the Mediterranean building stock, was modelled in TRNSYS environment. Building simulations are run for the current situation using weather data from the EnergyPlus database (Building Technologies Office of U.S. Department of Energy's, n.d.) and for the years 2050 and 2080 using generated future weather data. The selection of two specific future timeframes up to 2080 is based on the general assumption that a building built in

2010-2020 has a useful life of at least seventy years (Cellura et al., 2013b; Cellura et al., 2014).

Future climate weather data are constructed using climate change predictions in compliance with the A2 emission scenario developed in the IPCC TAR. In particular, scenario A2 was chosen as basis of the study, because it is the highest emissions scenario. For example, it is characterized by higher emissions in both the carbon dioxide (29.1 GtC/year) and the fluorocarbons (753 GtC_{eq}/year). Moreover, this scenario is characterized by the highest population growth (15 billion in 2100) and by a slow economic development (the assumptions on the average annual growth rate of gross domestic product (GDP) is 2.2%, which is lower than the 2.9% average annual growth rate observed between 1970 and 1995).

The IPCC scenarios do not include climate change predictions but they represent possible development pathways of human activities to be used as a baseline for a climate change modelling. On the other hand, several global climate models for simulating the effects of climate change have been developed and their results are available online and integrated into the IPCC Assessment Reports. In this study, data available from IPCC were manipulated through the CCWorldWeather Generator tool, developed by Southampton University (Southampton University, 2010), that allowed to extrapolate fixed ranges of variations for the climate change-inducing variables. This set of data were used as input to an implementation of the "morphing" method, proposed by Belcher et al. (2005) allowing to modify a hourly weather data for the desired site on the basis of forecasted factors and disturbances to climate.

In detail, this method requires that each climatic variable (x_o) of the current weather data is modified by one of the following operations:

1. a shift;
2. a linear stretch;
3. a combination of a shift and a stretch.

In particular, an operation of shifting is used for variables for which the climate model identifies an absolute monthly variation to the mean. For example, the future hourly atmospheric pressure (p) can be calculated directly from the present hourly value of the atmospheric pressure (p_0) and from the monthly increment in atmospheric pressure (Δp_m), provided by the climate model, as in eq. 1:

$$p = p_0 + \Delta p_m \tag{1}$$

where the subscript “0” identifies current weather data files, the subscript “m” identifies monthly data, the absence of subscripts identifies future data.

A stretch is used when the climate change predictions are reported as a fractional monthly change. For example for the global horizontal radiation (r) the forecasts provide an absolute increment for monthly average solar shortwave flux received at the surface (Δr_m). A scaling factor for the month m (α_{rm}) is obtained from the absolute variation (Δr_m) and the monthly mean ($\overline{r}_{0m}$) from the observed baseline climate as in eq. 2:

$$\alpha_{rm} = 1 + \frac{\Delta r_m}{\overline{r}_{0m}} \tag{2}$$

This scaling factor is then applied to all months m in the time series using eq. 3:

$$r = \alpha_{rm} \cdot r_0 \tag{3}$$

where r_0 is the hourly value of the current global horizontal radiation, r is the dynamically varied global horizontal radiation.

Finally, a combination of a shift and a stretch is used for climatic variables, such as dry-bulb temperature, to reflect changes in both the daily mean and the maximum and minimum daily values. In particular, for the dry-bulb temperature the climate change scenario provides the monthly daily mean temperature variation due to climate change (Δt_m), the monthly daily maximum temperature variation ($\Delta t_{max,m}$) and the monthly daily minimum temperature variation ($\Delta t_{min,m}$).

Firstly, using $\Delta t_{max,m}$ and $\Delta t_{min,m}$, the scaling factor for the dry-bulb temperature (α_{tm}) is calculated through eq. 4 using monthly mean values from both the current and future data:

$$\alpha_{tm} = \frac{\Delta t_{\max,m} - \Delta t_{\min,m}}{\overline{t}_{0\max,m} - \overline{t}_{0\min,m}} \tag{4}$$

where $\overline{t}_{0max,m}$ and $\overline{t}_{0min,m}$ are the monthly mean of the current daily maximum temperature and the monthly mean of the current minimum daily temperature, respectively.

Afterwards, the future hourly variable dry bulb temperature is calculated through eq. 5:

$$t = t_0 + \Delta t_m + \alpha_{tm} \cdot (t_0 - \overline{t}_{0m}) \tag{5}$$

where t_0 is the present hourly dry-bulb temperature and $\overline{t}_{0m}$ is the monthly mean temperature variation in the current climate for the month m.

All weather data used are for the city of Naples. This location is characterized by a comfortable climate, with mild winters and moderately hot summers. As shown in Figure 1, the daily peak value of the horizontal solar radiation varies during the year between 536 Wh/m^2 (in December) and 968 Wh/m^2 (in July) while the outdoor temperatures can range between 35 °C and -3 °C.

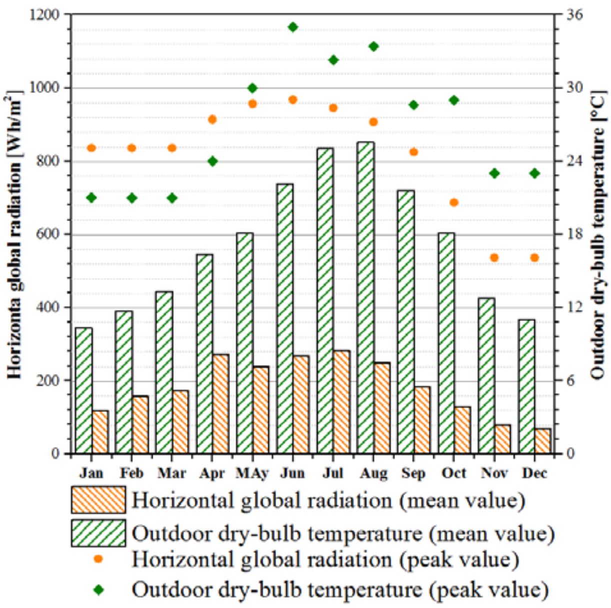

Figure 1: Outdoors temperature and horizontal solar radiation trends for Naples, Italy.

Although not representative of all the locations of the Mediterranean, this climate is very close to a wide range of coastal Mediterranean sites. Figure 2 reports the heating degree days (HDD), the cooling degree days (CDD) and the annual mean of the global horizontal radiation (GHR) for Naples and for some others Mediterranean locations.

As shown in Figure 2, the climate of Naples is very similar to the Mediterranean coastal cities in the red area between the latitude of 38° (Lisbon and Athens) and latitude of 43° (Marseille). For example for Rome and Barcelona the average solar radiation is different by 1% compared to that measured in Naples; for these cities, compared to Naples, the CDDs vary for 45 dd and 62 dd, respectively, while the HDDs vary by less than 4%. Bari is the city with the lowest variation in the HDDs (+2%) while the CDDs and the GHR vary of 23 dd and 17 Wh/m^2, respectively. For Lisbon and Cagliari the HDDs difference reaches 8%, while the CDDs and the GHR vary for less than 40 dd and 20 Wh/m^2, respectively.

Finally, Athens (1568 dd) and Marseille (2308 dd) are the cities with the highest variation in the HDDs, -17% and +22%, respectively.

A low-rise building model is used as ideal case-study. The building is a residential house with four occupants maximum inside it at the same time. Only moderate electrical loads are included (2.5 W/m^2) while lighting installed power is 10 W/m^2.

As shown in Figure 3, it is one-storey high with a total heated area of 100 m^2. The building envelope features were chosen in compliance with the minimum requirements for a new residential building in Italy (Italian Parliament, 2015). Its representiveness in the Mediterranean area is ensured by the accordance with the buildings energy efficiency codes in force in Portugal (Portuguese Parliament, 2006) and Spain (Spanish Parliament, 2009).

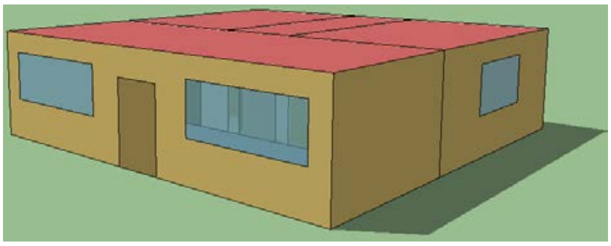

Figure 3:The building model used as case-study.

Table 1 reports the main building features. The windows are made of a double panel insulated glazing, the average global window *U*-value is 2.1 W/(m^{2}K), while the Solar Heat Gain Coefficient (SHGC) is 0.49. U-value for vertical surfaces is 0.34 W/(m^2 K), 0.33 W/(m^{2}K) for the roof and 0.38 W/(m^{2}K) for the floor. All walls have an internal mass layer (brick, 30 cm for external walls) and external insulation (5 cm for the walls and 8.5 cm for the roof). For the external walls a light grey colour (absorptivity and reflectivity coefficients equal to 0.6 and 0.2 respectively) is considered.

Table 1: Building features and thermal properties of the building envelope.

Building Features	
Heated Floor area [m^2]	100
Volume [m^3]	270
S/V overall ratio [m^{-1}]	0.73
Window to wall ratio	0.12

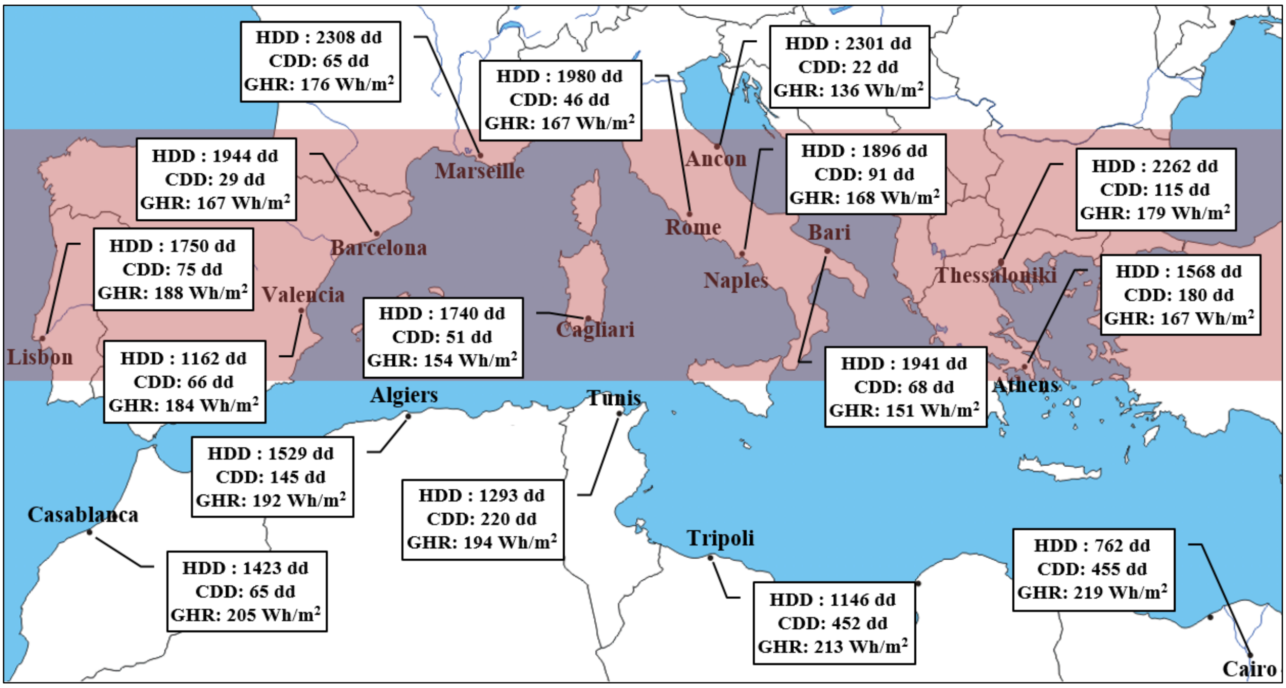

Figure 2: Heating degree days, cooling degree days and global horizontal radiation for some Mediterranean cities.

Natural ventilation is modelled through TRNFLOW (Transsolar, 2009), that integrates the multi-zone airflow network in TRNSYS environment. In particular, TRNFLOW models the building as a network of nodes and airflow links between them. The nodes represent the rooms and the building surroundings. Using air mass conservation balances in each node and taking into account meteorological variables, a system of non-linear equations is solved to determine the node pressures and the airflow through each link (Weber et al., 2003). In detail, the ventilation strategy modelled in TRNFLOW provides the opening of windows when external temperature is higher than 18°C and lower than 26°C and when indoor air temperature is higher than 20 °C.

The results of the analysis are discussed through the use of the following indicators:

- HDD and CDD. They are used to analyse the climatic data in order to study the relationship between the climate change and the demand for energy needed to heat or cool a building. In particular, the HDD and the CDD are calculated through the following equations as given in (Day, 2006):

$$HDD = \sum_{n=1}^{365} \frac{\sum_{j=1}^{24} \left(t_{ref} - t_j\right)_{\left(\left(t_{ref} - t_j\right) > 0\right)}}{24} \qquad (6)$$

$$CDD = \sum_{n=1}^{365} \frac{\sum_{j=1}^{24} \left(t_j - t_{ref}\right)_{\left(\left(t_j - t_{ref}\right) > 0\right)}}{24} \qquad (7)$$

where, t_{ref} is the reference temperature, t_j the outdoor temperature in the j^{th} hour and n is the day of year. Only positive values are considered. The reference temperature is the outdoor temperature at which the heating or cooling systems do not need to be activated in order to maintain comfort conditions (Day, 2006). In particular, for the HDD and CDD, according to the heating and cooling set-points modelled, a reference temperatures of 20 °C and 26 °C, respectively are considered;

- variation of ideal thermal heating and cooling energy demand in comparison to current data in order to analyse the effect of climate change on building energy performance;
- availability of ventilative cooling calculated as the number of hours in which the external conditions allow the opening of the windows in accordance with the adopted ventilation strategy;
- potential of energy saving due to the use of ventilative cooling strategies.

Results

In this section, based on the assumptions made in the previous section, results on the future climate projections and the potential of ventilative cooling in counteracting the future climate change are presented.

Results on future climate projections

Table 2 shows the monthly average values of climate variables (dry-bulb temperature, global horizontal radiation and relative humidity) for the baseline climate data and for the results of future climates in 2050 and 2080. In particular, for Naples the results show an increase of the average monthly temperature of around 8% every 30 years. The months that have the greatest increase of dry bulb temperature are August and September, in particular in these months temperature is expected to increase by 2.7 °C and 2.4 °C in 2050 and 4.9 °C 4.5 °C in 2080, respectively.

The global horizontal radiation in 2080 compared to the current situation will increase by an average of 7%, with a maximum increase of 15% for the month of August.

Relative humidity will not report high variations in neither 2050 nor 2080. Considering the 2080 analysis, April and August are the months characterized by the highest relative humidity change from the current situation, accounting for +1.5% and -2.7%, respectively. Considering the climatic forecasts for 2050, the relative humidity change from the current situation is between + 1.5% (April) and -1.5% (October).

Table 2: Monthly average values of dry-bulb temperature, global horizontal radiation and relative humidity.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dry-bulb temperature [°C]	**Today**	10.4	11.8	13.4	16.4	18.1	22.2	25.0	25.6	21.6	18.2	12.8	11.0
	2050	11.8	13.0	14.5	17.6	19.5	23.9	27.4	28.3	24.0	20.0	14.7	12.8
	2080	13.0	14.3	15.8	18.8	20.8	25.6	29.4	30.5	26.1	21.7	16.1	14.1
Relative humidity [%]	**Today**	71.8	69.7	71.4	66.5	67.8	68.8	69.6	71.0	75.9	68.2	76.2	80.9
	2050	72.0	70.2	72.4	67.5	67.8	69.7	69.7	72.0	75.8	67.2	76.2	80.9
	2080	71.8	70.2	72.4	67.5	68.8	68.8	67.7	71.9	75.8	67.2	76.2	80.4
Global horizontal radiation [Wh/m^2]	**Today**	120.6	158.3	174.3	272.6	239.3	268.9	283.2	251.3	183.3	129.9	79.9	71.1
	2050	123.0	162.9	176.3	276.0	247.1	279.9	305.6	259.2	190.3	134.4	81.2	72.2
	2080	125.3	166.1	180.3	282.1	250.4	295.5	324.5	272.6	194.6	136.6	82.6	73.1

Table 3 and 4 show, respectively, HDD and CDD in Naples for the current situation and for the two future time frames. In particular, the climatic analysis shows that for the current situation the yearly HDDs (1891 dd) are approximately 20 times the yearly CDDs (91 dd).

In the futures scenarios the CDDs are characterized by an increasing trend while a decreasing trend characterises the HDDs. Between the current situation and 2050, the increase in the yearly cooling degree hours is +127% (yearly CDDs equal to 207 dd), whereas in the same period the decrease in the yearly HDDs is 19%. Considering the climate projection for 2080, the results show the same trends both in the rise of the CDDs and in the reduction of the HDDs. In particular, in 2080 yearly HDDs will decrease by 33% while the yearly CDDs will increase by 298%. However, despite these variations in 2080 the annual HDDs (1263 dd) will be even greater than the annual CDDs (364 dd).

August and November are the months characterized by the largest changes in the degree days. Considering the climate forecasts for 2080, in August the CDDs will increase by 102 dd compared to the current situation, while in November the HDDs will decrease by 42%. In detail, considering the same future scenario, in August the monthly average temperature will increase by about 19% (the relative humidity and the horizontal global radiation will vary, respectively, of about 1.3% and 8.5%), while in November the monthly average temperature will increase by about 28% (the relative humidity will not vary and the horizontal global radiation will vary of about 2.8%).

Table 3: Heating degree days for the current situation, 2050 and 2080

	HDD [dd]		
	Today	**2050**	**2080**
Jan	335.96	286.48	249.36
Feb	319.42	280.82	246.62
Mar	286.68	243.42	206.7
Apr	186.39	153.01	118.3
May	89.11	65.99	45.1
Jun	25.38	11.97	3.83
Jul	2.56	0.21	0
Aug	0.71	0	0
Sep	18.91	4.15	0.78
Oct	86.71	52.22	28.22
Nov	220.58	166.31	127.58
Dec	323.93	273.98	236.94
Heating period (From 15/11 to 31/03)	1393.93	1182.58	1015.70
Tot	1896.34	1538.56	1263.43

Table 4: Cooling degree days for the current situation, 2050 and 2080

	CDD [dd]		
	Today	**2050**	**2080**
Jan	0	0	0
Feb	0	0	0
Mar	0	0	0
Apr	0	0	0
May	1.94	4.73	10.45
Jun	19.04	31.8	51.29
Jul	29.1	68.41	115.03
Aug	38.16	85.23	140.61
Sep	2.7	15.27	40.47
Oct	0.33	1.32	5.75
Nov	0	0	0
Dec	0	0	0
Tot	91.27	206.76	363.6

Results of building simulation

Figures 5 and 6 show, respectively, the monthly thermal energy demand for heating and cooling for the current situation and for the two future forecasts in a scenario that does not include any ventilation strategies. The simulated energy requirements for the current situation indicate that the yearly energy demand for heating (around 41.4 kWh/(m^{2}year)) is greater than the cooling demand (about 25.2 kWh/(m^{2}year)). In particular, the months that need more heating are January (9.4 kWh/m^2) and December (10 kWh/m^2), while the months of July and August require the highest cooling demand, respectively 8.6 kWh/m^2 and 8.5 kWh/m^2.

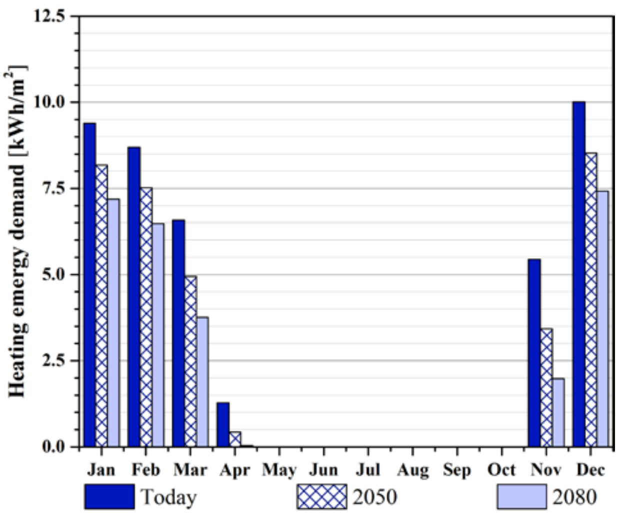

Figure 5: Heating demand.

As shown in Figure 6, the results indicate an increase in the cooling energy requirement of the building amounting to 53% in 2050 and to 103% in 2080. July is the month in which the increase of cooling energy demand is highest, in particular, it increases by 3.3 kWh/m^2 in 2050 and 6.1 kWh/m^2 in 2080. Heating energy requirement is expected to decrease by 20.2% in 2050 and 35.1% in 2080.

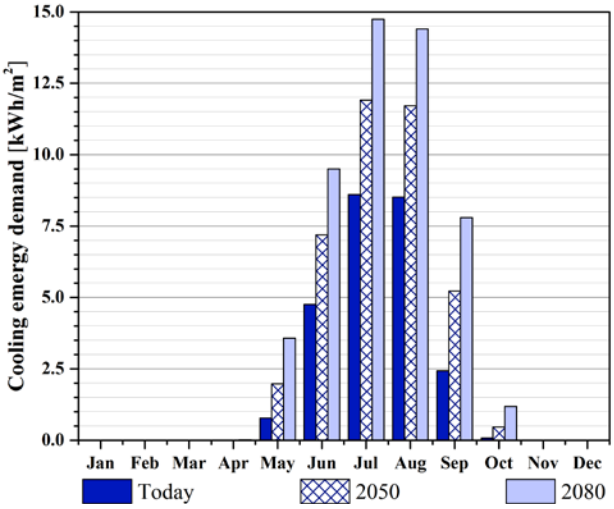

Figure 6: Cooling demand.

Results on the potential of ventilative cooling

In order to quantify the beneficial potential of ventilative cooling on building performances, the natural ventilation strategy discussed in the methods section was implemented. Figure 7 shows the number of hours in which the windows are open. For the current climate situation, the availability of ventilative cooling is equal to 23.5% of the total yearly hours. The months in which ventilative cooling availability are highest are June and September. In particular, in these months the number of hours in which ventilative cooling can be available is equal to 409 h, (56.7% of monthly hours) and 496 h (68.9% of monthly hours), respectively.

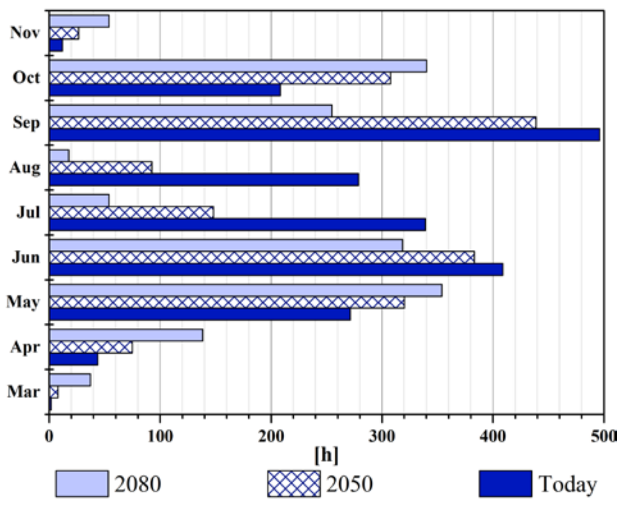

Figure 7: Availability of ventilative cooling.

As shown in Figure 7, the yearly number of hours in which the ventilative cooling is available is reduced over the years. In particular, the results show a reduction in the ventilative cooling availability of about 13% every 30 years, from 2060 h in the current situation to 1569 h in 2080. During summer the reduction in the hours of availability of ventilative cooling amounts to 403 h in 2050 and 637 h in 2080. Moreover, the results show that the applicability of natural ventilation strategies during mid-seasons will significantly increase over the years, e.g. in October the availability of ventilative cooling compared to the current climate situation will increase by about 47.7% in 2050 and by 63.3% in 2080.

The simulation results show that the ventilative cooling has not appreciable effectiveness in reducing the heating energy requirements over the years, e.g. for the current climate situation the natural ventilation strategy causes an increase of the yearly heating energy requirement equal to 0.5% (+0.22 kWh/(m^2 year)).

Table 5 shows the monthly cooling thermal demand for ventilation scenarios and the energy savings due to the use of ventilative cooling compared to the scenarios without ventilation.

Ventilative cooling could reduce the cooling energy requirements from 25.52 kWh/(m^{2}year) to 7.9 kWh/(m^{2}year). The most significant reductions are available in mid-seasons. Despite high temperatures during daytime, some benefits in terms of energy use are available also in summer (a reduction of 5.9 kWh/m^2 in July and 3.9 kWh/m^2 in August).

The results about future forecasts indicate that energy savings due to the use of natural ventilation strategies will be about 17 kWh/(m^{2}year) both in 2050 and in 2080. However, ventilative cooling will not be able to counter the increase in annual demand for cooling energy that will amount to 13.4 kWh/m^2 in 2050 and 25.7 kWh/m^2 in 2080 compared to the current situation. Currently, ventilative cooling could reduce the annual energy demand for cooling by 69% if compared to the scenario without ventilation, while it is expected that in 2050 and in 2080 it could reduce cooling energy use by 45% and 34% only, respectively.

Discussion

The results suggest that future global warming will have a significant impact on the climate in the Mediterranean basin.
The climate analysis of the weather data shows that the increase in yearly cooling requirements is much greater than the decrease in the heating requirements. The mid-seasons will be most affected by this change: for example considering the 2080 forecasts in the month of May a reduction of 49% of heating requirements is expected, while the cooling requirements will increase by about 5 times compared to the current situation.

Table 5: Cooling demand for the ventilative cooling scenario

Cooling Demand									
	Today			**2050**			**2080**		
	With ventilation [kWh/m^2]	**Without ventilation [kWh/m^2]**	**Energy saving [kWh/m^2]**	**With ventilation [kWh/m^2]**	**Without ventilation [kWh/m^2]**	**Energy saving [kWh/m^2]**	**With ventilation [kWh/m^2]**	**Without ventilation [kWh/m^2]**	**Energy saving [kWh/m^2]**
Jan	0	0	0	0	0	0	0	0	0
Feb	0	0	0	0	0	0	0	0	0
Mar	0	0	0	0	0	0	0	0	0
Apr	0	0	0	0	0	0	0	0.02	0.02
May	0	0.78	0.78	0.03	1.97	1.94	0.18	3.58	3.40
Jun	0.48	4.76	4.28	1.61	7.19	5.58	3.79	9.50	5.71
Jul	2.76	8.60	5.84	8.67	11.91	3.24	12.35	14.75	2.40
Aug	4.59	8.52	3.93	9.81	11.72	1.91	12.64	14.40	1.76
Sep	0.08	2.43	2.35	1.14	5.23	4.09	4.48	7.79	3.31
Oct	0	0.09	0.09	0.02	0.46	0.44	0.19	1.19	1.00
Nov	0	0	0	0	0	0	0	0	0
Dec	0	0	0	0	0	0	0	0	0
Tot	7.91	25.17	17.26	21.27	38.48	17.21	33.64	51.22	17.58

The simulation results show that the cooling demand in a typical Mediterranean building could increase by about 13 kWh/(m^{2}year) every 30 years, reaching the value of 51.2 kWh/(m^{2}year) in 2080 compared to 25.2 kWh/(m^{2}year) in the current situation. At the same time, heating demand will vary from 41.4 kWh/(m^{2}year) to 26.9 kWh/(m^{2}year) (-35%).

Since the trend expected includes lower heating and higher cooling demands in buildings, natural ventilative cooling strategies could have a key role in improving buildings energy performance in future climates. In particular, the results show that in summer the availability of ventilative cooling, according to the future climatic projections, could be reduced by around 39% in 2050 and about 62% in 2080 compared to the current situation. However, although the availability of ventilative cooling is expected to decrease during summer, it will increase significatively during mid-seasons. For example, in May and October, the availability of ventilative cooling will increase respectively by 18% and 48% in 2050 and by 30% and 63% in 2080. The same trend is traceable in energy use reductions, e.g. in August, considering 2080 results, the energy savings due to ventilative cooling will decrease by 123% while in April it will increase by 77%.

Conclusions

The impact of climate change on building energy performances and the potential of natural ventilative cooling as passive cooling technique in the Mediterranean area are presented for the current situation and for two future scenarios.

The paper is aimed towards buildings designers and practitioners of non steady-state building simulation, since the evolution of predicting weather data for the next decades is one of the research challenges of the years to come.

In particular, in order to respond to the significant increase in the energy consumption of buildings caused by the global climate change, the use of passive techniques to reduce the energy demand of buildings will be fundamental. Ventilative cooling can be an effective technique in reducing the energy demand for cooling in the Mediterranean area but in the long-term future the proposed solution cannot be able to counteract the increase of the energy required for cooling. Moreover, natural ventilative cooling will be less relevant in the future than today during summers, instead it will be more effective during mid-seasons.

Nomenclature

CDD = cooling degree day

GDP = gross domestic product

GHR = global horizontal radiation

HDD = heating degree day

IPCC = Intergovernmental Panel on Climate Change

IPCC TAR = Third Assessment Report of the Intergovernmental Panel on Climate Change

p = predicted value of the atmospheric pressure

p_0 = present value of the atmospheric pressure

r = predicted value of global horizontal radiation

r_0 = present value of global horizontal radiation

t = predicted value of dry-bulb temperature

t_0 = present value of dry-bulb temperature

$\overline{t}_{0max}$ = monthly mean of the current daily maximum temperature

$\overline{t}_{0min}$ = monthly mean of the current minimum daily temperature

t_j = outdoor temperature in hour j

t_{ref} = reference temperature

x_0 = current hourly climate variable

αr_m = scaling factor in monthly global horizontal radiation for the month m

αt_m = scaling factor for the dry-bulb temperature

Δp_m = monthly increment in atmospheric pressure

Δr_m = absolute increment for monthly average solar shortwave flux received at the surface

Δt_m = predicted monthly daily mean temperature

$\Delta t_{max\ m}$ = predicted monthly daily maximum temperature

$\Delta t_{min\ m}$ = predicted monthly daily minimum temperature

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