Climatic potential maps of ventilative cooling techniques in Italian climates including resilience to climate changes

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Abstract. Building energy consumptions for space cooling is a globally rising voice. Considering the need to reduce the total energy consumptions and related GHG, alternative solutions based on natural heat sinks are essential. Unfortunately, these technologies, such as passive cooling systems, are very local specific and their geo-climatic applicability needs to be studied to correctly choose and integrate them since early design phases. The paper studies the distribution of climate-related demand for cooling in the Italian context, by mapping local CDH (Cooling Degree Hours) together with the local potential of ventilative cooling dissipative technologies (e.g. controlled natural ventilation), for present and future climate conditions. A geo-referenced matrix – considering all the 7978 Italian Municipalities – of typical meteorological years will be generated and further analysed on hourly base by developing Python scripts. Results of this analysis are visualized in devoted maps of applicability able to underline the local expected potential of wind-driven ventilative solutions. These maps can act as a reference toolkit for designers considering early-design evaluations. Finally, the expected resilience of local climate-potential of these technologies to climate changes is analysed.

1. Introduction
Energy consumption for space cooling is a rising voice in both industrialised and emerging countries due to several factors connected with international style of building, comfort expectations, higher internal gains, and increasing in air temperatures [1, 2]. Even if the average EER of mechanical systems is higher than in the past, this improvement is not sufficient alone to invert the consumption trend [3]. Low-energy solutions, such as ventilative cooling, are hence essential. Passive and low-energy technologies may constitute, in fact, valid alternative solutions to mechanical systems, especially in mid-seasons and for non-peak conditions [2,4]. Furthermore, these solutions are in relation with regionalism and local comfort culture being able to be accepted by populations [5]. Unfortunately, these solutions – such as heat gains dissipations through thermal sinks (air, water, ground, and night sky) – are local specific and need, to be correctly chosen and dimensioned, an attentive analysis of their geo-climatic applicability in each location since early-design phases [4,6]. This paper focuses on CNV (controlled natural ventilation) due to wind-driven differences in pressure between openings.

Previous indicators to define the climate potential of CNV were defined for night cooling analyses. In particular, considering office non occupation hours, the CCP (climatic cooling potential) was introduced in [7] by defining the night degree hours between a sinusoidal-varying internal temperature and the external one. A fixed ACH (air exchange rate) was defined assuming 6 [h⁻¹] for calculating the ventilative cooling potential. Furthermore, a different method, based on the calculation of residual CDH, was also proposed in [8,9]. This consider both the structural cooling potential, adopting daily cycles, and the comfort ventilation potential due to wind-induced air movements. Nevertheless, this approach does not define at present the sensible cooling dissipation potential. Differently, this paper introduced an indicator to define the local climatic sensible cooling dissipation potential of CNV considering the potential air exchange rate due to wind forces. This constitutes the first report of a large research that is
under development including a detailed method to calculate the pressure coefficient distribution on building facades.

2. Methodology

The distribution of local cooling needs may be analysed on a climatic point of view by using the CDH (cooling degree hour) indicator [10], which transposes the HDD (heating degree days) indicator for the cooling season, here assumed to be from June to August. This index is directly related to the expected energy needs of buildings [11] and may be used to define the local cooling need intensity. For the purpose of this paper, CDH were calculated to analyse the original need for cooling to be climatically covered by CNV techniques. The calculation base temperature was assumed as 26°C [8] and the environmental one was defined by the local TMY (typical meteorological year) produced by Meteonorm v7.1 for each location adopting the period 1991-10 for irradiation and 2000-9 for temperatures.

Furthermore, the local potential of wind-driven CNV was defined in terms of expected thermal dissipation by natural inducted air exchanges. For this paper a potential indicator is introduced by calculating the hourly CDH dissipation potential of the external air coupled with the airflow inducted by wind-driven cross ventilation – see the indicator reported in equation (1).

\[
Q_{sens} = \sum_{n=1}^{cool.seas.hs} \left\{ 0 \iff \theta_{env,n} > \theta_{comf} \lor \theta_{comf} - \theta_{env,n} < 3 \\
(q_n * 3600) * \rho_{air} * c_{air} (\theta_{env,n} - \theta_{comf}) \iff \theta_{comf} - \theta_{env,n} \geq 3 \right\} \text{[Wh]} \tag{1}
\]

Where the wind-driven airflow rate \( q \) [m³/s] is calculated according to eq. (2) [10,12], \( \rho_{air} \) is set to 1.2 [kg/m³] and \( c_{air} \) to 0.28 [W/kg°C]. The assumed comfort temperature is set for this geo-climatic analysis to 26°C [8], even if sinusoidal variations around 24.5 were also introduced in literature for night ventilation in office buildings [7]. The calculation was performed from June to August.

\[
q_n = v_{w,n,h} * c_d * A * \sqrt{\Delta_{cp}} \text{ [m³/s]} \tag{2}
\]

Where the wind velocity of hour \( n \), get from the TMY, is reported to the considered opening mid-point height and site boundary conditions by using the well-known power law expression – see [13] –, and assuming an urban calculation site (medium density) and a window height of 5m from the ground. Nevertheless, to prevent excessively high airflow velocities in internal spaces, this value is limited to a maximum velocity of 1.5 m/s [14]. The discharge coefficient is set to 0.6 [12], while the opening area is here assumed as 1m² to be easily scalable by designers by considering the areas of inlet and outlet windows located on different facades – see [10]. A set of fixed pressure differences (\( \Delta_{cp} \)) between openings are here assumed in the domain \{0.1;0.2;0.3;0.4;0.5;0.6;0.7;0.8\} to cover different local boundary conditions and building geometries. Nevertheless, different methodologies may be used to get hourly defined values for a specific building geometry and/or surrounding conditions, e.g. by assuming tabular approaches [13] or by using parametric tools, such as CPCalc+ [15], which is now under upgrading. In Section 4 - Discussion, the tabular approach is applied to a sample cubic building by calculating, for each activation hour, the wind incident direction on each facades and the correspondent hourly \( c_p \) value. Two cases were analysed to calculate the correspondent \( Q_{sens} \) potential considering that windows are localized respectively on the N-S façades and on the E-W ones. Results are hence compared with the ones reported in Section 3. Furthermore, the priority of CNV adoption, based on the potential of wind-driven ventilation, can be estimated by combining the obtained Q values with the local cooling climate demand intensity (CDH), by adapting a tabular approach already presented for evaporative cooling – e.g. [16]. Tab. 1 describes the selected classes of applicability – see the CDH boundaries in [17]. Geo-referred maps were produced by using QGIS open software v.3.4.4. The same approach was applied adopting the IPCC future climate scenario A1B for year 2030, compatible with mid-impact climate changes in line with RCP6.0 – TMY were generated by using Meteonorm [18] in order to have the same base climate references, considering the Italian Municipalities with more than 50000 inhabitants (ISTAT database 2017). Meteonorm adopts the IPCC scenarios FAR [19] including
anomalies in temperature, precipitation and global radiation, being based on climate model predictions, these data are subject to uncertain. The comparison with current TMY is described in Section 4.2.

Table 1. Classification to define the local priority map of CNV wind-driven geo-climatic potential

| ▼cl. CDH 26 ▼cl. CDH 26 | 0-1000 | 1000-2500 | 2500-5000 | >5000 |
|-------------------------|--------|-----------|-----------|-------|
| ▼ Cl. ∑Q [kWh]          |        |           |           |       |
| < 500                   | VL     | VL        | VL        | L     |
| 500-1500                | VL     | L         | L         | M     |
| 1500-2500               | L      | M         | M         | H     |
| 2500-5000               | M      | H         | H         | VH    |
| >5000                   | H      | VH        | VH        | VH    |

3. Analyses

Considering the 7978 Italian Municipalities, the local climatic cooling need indicator (CDH 26) is calculated and plotted in the map of Fig. 1(a). As expected, the distribution of these values is not homogenous, but follows the local latitude with local variations due to site altitude – e.g. Alps mountains (North: from West to East) and Apennines from North to South.

Figure 1. (a) Distribution of local CDH 26 for current TMY data for the entire Italian Municipalities database. Sample values were plotted on the right to improve readability of intermediate cases.

3.1. Definition of local wind-driven CNV potential

According to the indicator described in the methodology section, the local cooling dissipative potential was calculated for all locations considering the adopted set of differences in pressure coefficients. Fig. 2 illustrates the obtained values for 5 of the 8 considered ∆𝑐𝑐𝑝𝑝 values – {0.1;0.3;0.5;0.7;0.8}. Nevertheless, these values were averaged on hourly base [av. Whact.hr], by dividing the Q by the number of CNV activation hours – see Fig. 2(a) –, to make results directly readable by designers, allowing comparisons with hourly averaged cooling energy needs of sample buildings. These maps illustrate that: firstly, the number of activation hours is higher where the local environmental air is low (below the activation threshold) and so this parameter has a counterrtrend in respect to CDH. Secondly, it is shown that the average hourly cooling dissipative potential is higher in Central Regions (South of Tuscany, North of Lazio, Umbria and Marche), South of Italy, Sardinia and in alpine North-West locations. Thirdly, that ∆𝑐𝑐𝑝𝑝 higher than 0.3 already support high CNV potentiality.
Figure 2. (a) No. of CNV activation hours; (b-f) distribution of local cooling dissipative potential (average hourly values) for respectively a fixed ΔCₚ of {0.1;0.3;0.5;0.7;0.8}.

Furthermore, the priority map of CNV geo-climatic potential were generated according to Table 1. For this analysis the total dissipative cooling potential was assumed. Fig. 3 shows the map for a ΔCₚ of 0.5. This map underlines that the CNV climatic potential is high in almost all central and southern Italian municipalities, with special regards to non-coastal locations where CDHs are lower and both the number of applicability hours and the dissipative power are higher.
4. Discussion

4.1. Tabular Cp hourly calculation

The obtained hourly averaged Q-values, when $c_p$ are hourly calculated on the facades of a sample building by using the tabular approach, are reported in Figure 4, respectively for openings localised on the N-S façades, Fig.4(a), and on the E-W façades, Fig.4(b). Results show that E-W CNV orientations are slightly better in central Italy, while N-S ones in North and South locations. Tabular results can be compared with the fixed $\Delta c_p$ ones reported in Figure 2. Tabular Q-values are in between Fig. 2(c) and 2(d). Furthermore, Fig. 4(c) correlates for each location the tabular Q-value with the fixed $\Delta c_p$ one. Fixed $\Delta c_p$ are here defined by seasonally averaging the tabular hourly values. Very high correlations are underlined between these two approaches, suggesting that fixed $\Delta c_p$ maps can be a valid early-design approach to define the wind-driven CNV local climatic potential.

4.2. Climate changes

The potential effect of climate changes was hence checked. Figure 5 shows the variations in the priority CNV classes for the considered locations (Municipalities >50k inhabitants). Such as was also underlined in Fig. 1(b), changes are local specific without a direct visible correlation with current classes – see also
Fig. 5 (a) and (b). Nevertheless, the general distribution – Fig. 5(c) – shows a slight increase in extreme classes (VL, VH) and a general transposition from L to M values. Roughly speaking, it is possible to underline an increase in CNV potential in northern locations and a decrease in southern-east ones. This is due to the local growth of CDH, while the Q increases in north locations and decreases in south ones.

5. Conclusions
The paper reports a simple approach to define the local climatic potential of wind-driven CNV according to local climate data. Results confirm that the geo-climatic potential of this passive cooling strategy is very local specific, and has to be analysed since early-design phases. Furthermore, the proposed set of maps can be used as meta-design instruments by designers for this first analysis. The comparison between the average $\Delta c_p$ value and the hourly calculated ones shows that advanced approaches to define this variable are needed for specific considerations (opening orientations), while general considerations on climatic applicability may be done also on the fixed value domain. Finally, the effect of climate changes on the local potential of CNV was underlined. Thanks to this analysis it is possible to state that wind-driven CNV is expected to slightly growth in its potentiality also under a medium impact climate change scenario showing a local-related resilience to this perturbation phenomenon.

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