City, Territory
and Architecture

Developing a process-oriented approach towards Positive Energy Blocks: the wind-analysis contribution

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Abstract

Positive Energy Block (PEB) is an emerging paradigm to transform cities into low carbon cities. It is expected that buildings will become the main components of the future energy infrastructure. This scenario demands a structural integration of the cyclical environmental variables in designing our buildings and cities as a whole. However, such an integration continue to be rare due to the dominance of object-oriented approaches. This study contributes to reducing these difficulties by developing a process-oriented approach, focusing on the wind contribution. The assumption posed herein is that the transition towards PEBs should be an opportunity to redefine the rules to organise the built environment structure integrating energy and urban environmental qualities. A case study, involving three public school buildings located in three different urban patterns in Rome, illustrates a preliminary step in developing an integrated platform to orient strategic design solutions towards PEBs. This is done by developing and assessing three indexes: wind form index, wind thermal-loss index, and wind energy production index. The results point out the usability and limits concerning the approach adopted, stressing the relevance of an integrated platform to support decision-makers in planning the agenda to transform buildings as components of PEBs.

Keywords: Low carbon transition, Low carbon city, Positive Energy Block

Introduction

European Construction Sector Observatory (2018) reports that 75% of the buildings were built before 1990. Therefore, the improvement of the energy performance of existing buildings emerges as a priority in the UE context in order to achieve the mandatory NZEB target. Moreover, Positive Energy Blocks (PEBs) and Positive Energies Districts (PEDs) are now emerging as new paradigms to transform cities into Low carbon cities (Shnapp et al. 2020).

Though there is still no standard definition of PBEs, a PBE tentatively is a form of building aggregation composed of at least three buildings, which are so effective that they generate more energy than they consume

(Magrini et al. 2020). This new paradigm has been highlighted in recent studies as an opportunity to accelerate the decarbonisation of the building sector through creative energy relationships concerning buildings, urban and environmental features, (e.g., Cole and Fedoruk 2015; Bulut et al. 2016; Sibilla and Kurul 2020a). Therefore, it is expected that new and existing buildings and their urban environments will act as components of the future energy infrastructure.

However, how to put these paradigms into practice is an open issue. One reason is that the current energy renovation rate is between 0.4 and 1.2% (Esser et al. 2019). Consequently, achieving NZEB, PEB and PED target is not easy, and a new strategic approach is needed.

In this regard, the literature emphasises the lack of innovative socio-technical approaches (Hillman et al. 2018) and deficiencies in managing a long term vision concerning sustainable transformations (Salomaa and

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Juhola 2020) as important barriers to achieving significant results. Maciocco (2014) stressed that object-oriented approaches continue to prevail over the process- oriented ones. Nowadays, a great opportunity is offered by a new generation of environmental design approaches, based on advanced simulation tools, which emerge as a possible solution to manage the socio-technical re-organisation of the built environment.

Traditionally, the environmental design approach has been conceptualised as a method to integrate cyclical environmental variables into the design process at different stages. In other words, these cyclical variables are integrated components of the project. Hence, this approach has been emphasised to contrast the homologation and vulnerability of post-industrial urban environments and guide the transition toward a low carbon society (Knowles 2003; Butera 2013; Sibilla and Kurul 2018). In addition, it is expected that cyclical environmental variables will play a key role in the digital era, where environmental information can be gathered and used in real-to characterise future settlements' spatiality (Ratti and Claudel 2012).

Although the spatial and environmental issues have become a pillar of the European agenda (European Commission 2016), the environmental design approach is not common at the local level. It continues to be confined within the realm of experimental programmes (Caputo 2020). One of the reason is that cyclical environmental variables are not usually available for practical uses. Consequently, in designing cities and buildings, environmental design is used as an individual and occasional approach rather than a collective and structural methodology.

Against this scenario, in the last 2 decades, specialised software for solar and wind analysis have been disseminated at scale, allowing a new generation of architects and engineers to deal with a high level of complexity. Thus, it is expected that environmental information will be made more and more available on a common platform to optimise environmental cyclical variables' impact on strategic design solutions at scale.

The assumption posed herein is that the transition towards PEBs should be an opportunity to redefine the rules to organise the built environment structure; promoting the integration of cyclical environmental variables as a common practice in designing and managing buildings and cities, and delivering a new generation of buildings not only as a mere energy paradigm. Therefore, with reference to a prior work focused on solar analysis (Sibilla and Kurul 2020b), this study aims to develop a reference case where wind as a renewable energy source is taken into account to orient strategic design solutions towards PEBs.

The rest of the paper is structured as follows. "Methods" Section briefly overviews the literature on the wind as a renewable energy source in building and urban environments and explains the rationale of the work focused on PEBs. "Results" Section presents the approach, providing an overview of the main phases and a detailed description of the case study analysed. "Discussion: towards PEB configuration" Section presents the main results, while "Conclusions" Section discusses the potential implications in developing an integrated platform, focusing on the process towards PEBs. Limitations and possible future development are also presented.

Background

A large part of the literature is focused on the wind technology as a secure and clean energy system (Lacal-Arántegui 2019; Vargas et al. 2019). This technology is at the top of the fast-developing renewable energy sources worldwide (Allouhi 2019). In this scenario, the prediction of wind speed frequency distribution is a fundamental issue, which has captured the attention of many studies (Mathew et al. 2002; Vogiatzis et al. 2004). However, these studies have mainly focused on large-scale turbine applications; while few studies have explored wind energy production potential in urban areas (Culotta et al. 2015; Zhou et al. 2017). With this regard, Zhou et al. (2017) demonstrated the potential of a new generation of micro-wind turbines in low-rise residential buildings, focusing on how the airflow around low-rise residential buildings could be accelerated. In this regard, other studies have stressed relevant issues related to the noise production from wind turbines (Marini et al. 2017), the shadow produced by wind turbines on photovoltaic panels (Mamia and Appelbaum 2016), and economic profitability (Waewsak et al. 2017).

However, understanding wind as a renewable energy source not only can impact on energy infrastructure, but also on building energy consumption strategies and landscape qualities (Niachou et al. 2005; Wang et al. 2014; Ginelli and Pozzi 2018; Treu 2018). These are factors related to the development of a low carbon city. For this reason, several studies have analysed the behaviours of airflow in an urban environment and its implications not only in terms of energy system integration (Yuan 2018).

For example, the pioneering study elaborated by Arens and Williams (1977) highlighted how buildings energy consumption is influenced by airflow. Among other factors, the authors pointed out importance of the air pressure distribution on building surfaces due to the aerodynamics of the building influenced also by its surroundings. In detail, they demonstrated the relationship between airflow and energy loss. In addition, this study made evident that airflows' effect on heat transmission

depends on the building construction in terms of thermal resistance.

The implications between airflows and building insulation were replaced by Axaopoulos et al. (2015), who explored the optimum wall insulation thickness concerning wind speed and direction variation. The scope of this study was to determine the economic optimum insulation thickness, taking into account the statistical analysis of the wind direction and wind speed. Similarly, O'Sullivan and Kolokotroni (2017) stressed the relevance of airflow analysis for in-depth retrofit projects. Through a case study of wind dominant single-sided ventilation, the authors pointed out experimental measurements to suggest environmental and bioclimatic design solutions. This study demonstrated that the prediction of airflow phenomena helps to resolve many issues related to outdoor and indoor environmental quality.

With this regard, Evola and Popov (2006) proposed a method to provide reliable information about buildings' pressure distribution. Likewise, others tested methods to control the micro-climate of urban environments, which can be significantly influenced by urban geometrical characteristics (Straw et al. 2000; Dimoudi et al. 2013). For example, Straw et al. (2000) used wind tunnel tests to study wind speed and direction in different urban patterns. However, this approach is used on small-scale models.

An alternative method is represented by computational fluid dynamics (CFD), based on the resolution complex equations describing the flow field. Because this method involves large amounts of calculations, only a single building scale or a small community scale is used when simulating urban wind environments; thus, it is not suitable for large-scale simulations of wind environments at the city level (Xie et al. 2020). However, the CFD approach has become even more popular not only for its performance in terms of computational power, but also thanks to the user-friendly interface designed by software developers. As a result, CFD simulations are commonly used to design building structures and environmental forecasting for urban planning.

A different approach is based on experimental methods using sensors, which accurately measure local environmental conditions such as wind speeds and temperature in real-time (Heidarinejad et al. 2016). Therefore, as stressed by Wang et al. (2014), the visualization and spatial distribution of renewable energy sources is now extremely needed in order to make the integration of wind a common practice. Following this direction, the widespread usability of CFD software offers new collaboration opportunities between designers and specialists (Merlier et al. 2018). Therefore, the CFD analysis is emerging as an approach allowing designers to promote

urban ventilation as a component to orient strategic design solutions (He et al. 2020).

This work moves in the direction indicated by recent literature (Abanda et al. 2021) focused on developing guidelines and tools to operationalise benefits and strategies to achieving PEBs standard at the district level. In this work, the integration of wind analysis in the organisation of PEBs is an introductory phase for further approaches based on experimental methods, which accurately measure local environmental conditions such as wind speeds and temperature. The novelty of the work is twofold. Firstly, it promotes an integrated platform, where considerations concerning the use of wind as a source for infrastructural systems, building energy consumption strategies and urban environmental qualities can be synchronised. Secondly, it expands the strategic design implications in order to operationalise PEBs through a holistic approach.

Methods

This study is based on a CFD model, which can be beneficial for qualitative analysis of outdoor simulations (Good et al. 2008). However, numerical findings can be also considered from a quantitative perspective within specific contexts and limitations (Shirzadi et al. 2018, 2020). For example, the deviation between CFD results and wind tunnel is not significant for urban planar areas with low/medium density. This study was developed within these considerations and limitations. According to Tominaga et al. (2008) and Liu et al. (2018), the accuracy of CFD simulations was achieved by defining an appropriate grid typology.

Figure 1 shows boundary conditions adopted. Therefore, the mesh characterising the computational domain was divided into two regions: the centre region, which includes the building of interest and the outer part. The extension of the computational domain was set up according to literature (e.g., Tominaga et al. 2008), posing the building of interest at the centre of the domain, and extending this domain in x, y and z within a 1.5 radius with respect to the urban context analysed and the highest building, respectively. The computational domain is not static, but it varies with the wind direction. This allows us to better understand the impact of the surrounding on the air-flows. Additionally, the assessment of wind impact against different wind angles increases the accuracy of numerical results (Duncan and Soligo 2019).

To conclude the description of the boundary conditions, this study used the nearest meteorological station to collect wind data, considering only the winter period where the impact on thermal losses can be significant. The vertical profiles for velocity variation and turbulence variation were taking from Richards and Hoxey (1993). It
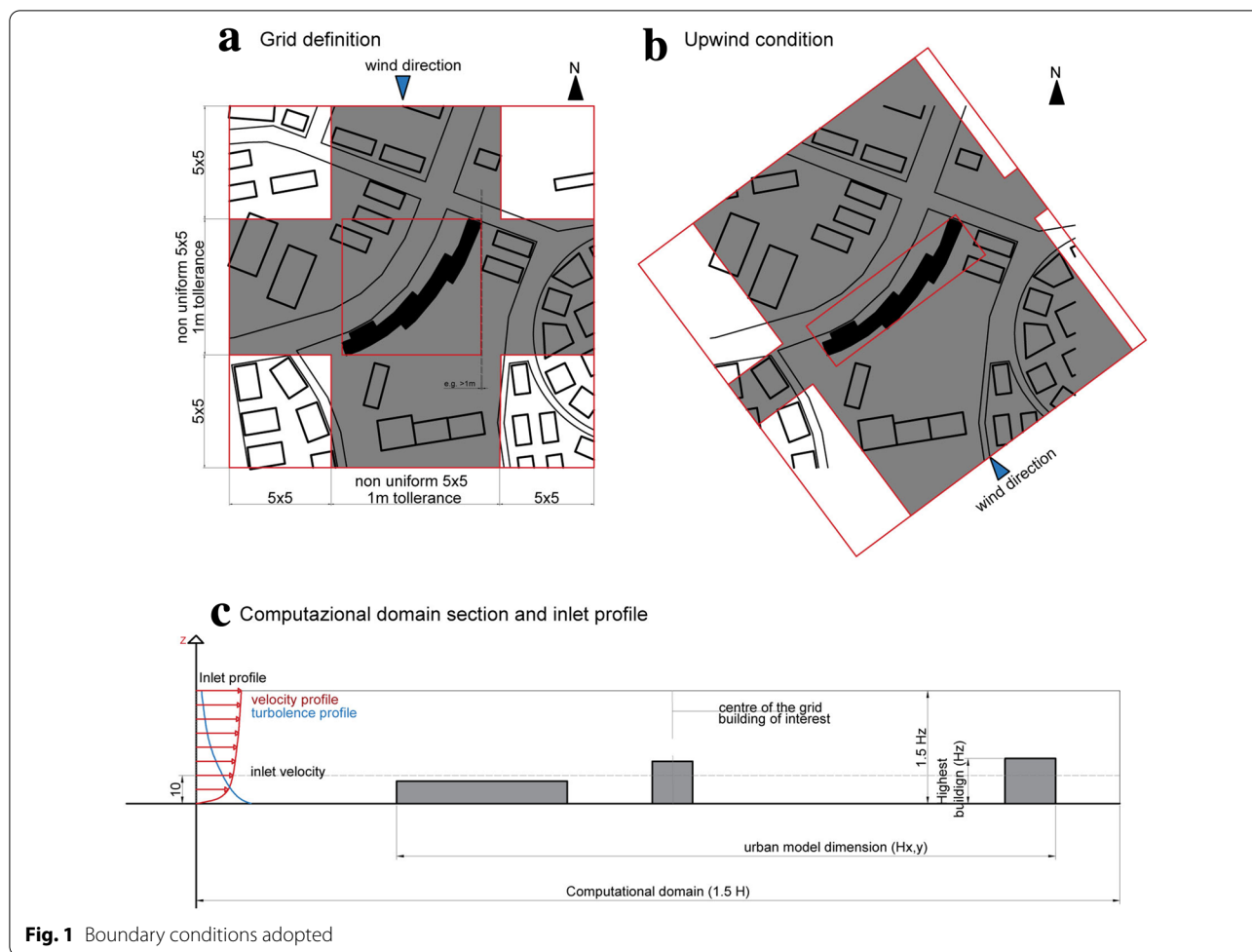
Fig. 1 Boundary conditions adopted

is well known that wind speed increases as a function of height, while the turbulence decreases.

About the calculation, DesignBuilder solves a set of equations (i.e., Navier Stokes equations) based on the conservation of mass and the conservation of momentum. Turbulence was considered through the k-ε turbulence model. This study does not introduce methodological variations to the numerical calculation; thus, it is not in the scope of this paper to get into the detailed mathematics since the algorithm adopted have been already validated. In this regard, additional details are reported in the DesignBuilder CFD instructional guide. Moreover, the reader can find additional information concerning CFD simulation in the literature (e.g., Blocken 2015).

The urban and building geometry was based on a simplified Level of Detail (LoD), focused on the main building's volumes. LoD refers both to international and national codes, typically adopted in BIM environments. Each LoD is characterised by a Level of Information (LoI), which establishes what type of data is needed to

carry out the analysis. By doing so, 3D geometry, performance and LoI were associated and integrated into a BIM platform for parametric management. Basic information concerning the thermal mass of the case studies was also collected. No other construction features are presented because they are irrelevant to the scope of this paper at this stage.

By doing so, the main factors affecting the CFD model were identified. Results obtained from the CFD simulation were used to develop a set of indicators to prioritise information concerning PEB configuration processes such as urban and building configurations, building retrofitting strategies and micro-wind integrations. These indicators, which vary with the LoD and LoI, are named and defined as follows:

$F_{w>0}$ (wind form index): this index is calculated as the ratio between F_2 (exposed surfaces under wind pressure) and F_1 total buildings surfaces. It represents the influence of building forms on wind-flows around the building of interest. A 3D visualisation was offered as a

tool to point out buildings' areas under criticalities and calculate the $F_{w>0}$.

$P_{w>2}$ (wind thermal-loss index): this index refers to the minimum value of wind velocity to have an impact on building thermal losses. This value was set at 2 m/s according to O'Grady et al. (2017), and its calculation was based on the ratio between P_2 (i.e., part of the building perimeter subject to wind velocity > 2 m/s) and P_1 (i.e., total perimeter). It was applied at the middle-high of the building (e.g., if the building is 20 m high, the calculation is conducted at 10 m).

$A_{w>5}$ (wind energy production index): this index refers to the minimum value of wind velocity to make the micro-wind installation feasible in terms of taking energy from winds. This value was set at 5 m/s, taking into account the test carried out by Singh and Rafiuddin Ahmed (2013) for a micro-turbine rated at 400 W with a 1.26 m diameter. The calculation was based on the ratio between A_2 (i.e., area of the roof invested by the wind with velocity > 5 m/s) and A_1 (i.e., total building covered area). It was applied at the top of the building plus one unitary dimension of the grid (i.e., 5 m).

In order to assess the reliability of the results, the concept of convergence was adopted. It allows us to establish how close we are to a solution for a specific required level of accuracy (Liu et al. 2018). In this study the accuracy was set at 10^{-5}. The information used in this procedure can be improved and expanded, making this approach replicable in other contexts, including other seasons.

Several simplifications were adopted herein. For instance, the urban pattern was only characterised by buildings and blocks, neglecting other components (e.g., vegetation, balcony). In addition, it is important to point out that, as stressed by Duncan and Soligo (2019), k-ε turbulence model used herein cannot deal with complex flows (i.e., flow separation and sharp changes in geometry). However, such simplifications were considered admissible in relation to the scope of this study and LoD adopted.

The following section describes three school buildings used as samples to test the procedure to implement a platform as a tool to synchronise cyclical environmental variables and strategic design solutions for PEBs.

Case study

Figure 2 shows a selection of school buildings belonging to the District XI of the Municipality of Rome. The Municipality is responsible for the process of maintenance and refurbishment of all of them. It is not a detailed map because it does not includes all school buildings belonging to the District. However, Fig. 2 suggests the high level of complexity that the process of maintenance and refurbishment requires both in terms

of financial resources and time. It also makes evidence about the impact that building schools have on the urban landscape of Rome. These buildings have also a significant impact on the environment, taking into account that a significant part of them was built before the first law concerning the control of energy consumption in buildings (i.e., Law no. 10/1978). Consequently, the buildings' energy performance is deficient, with a significant impact on the energy balance of the public building asset in Rome. Within this framework, the case study focused on three schools buildings, named as Case no. 1–3 (Fig. 2).

Following the approach described in the prior section, as a first step, the win-data concerning the Rome municipality was collected. The Airport of Ciampino station was used, being the nearest to the district analysed. Wind-Data was gathered from a website (i.e., https://www.windfinder.com), making free available real-time measurements, forecast, and statistics. Information with a particular focus on wind direction, frequency and air temperature is also accessible. This information is available on a daily, monthly and yearly basis. The wind statistics are based on actual observations from the weather station across the Globe.

Figure 3 shows both the urban pattern and the 3D geometry, which characterises the three case studies. The 3D geometry was defined through the main building's volumes. In terms of thermal mass, the case studies have different levels: Case no. 1 has a low thermal-mass building; Case no. 2 has a medium thermal mass; and Case no. 3 high thermal-mass. Figure 3 also includes wind data, pointing out three dominant wind directions across the heating period (i.e., from November to April): N, S, and SE, with a frequency of 20, 1%, 9, 7% and 7, 5%, respectively. In terms of average wind speed, the highest frequencies (i.e. > 50%) refer to 3 m/s (Fig. 3).

Table 1 shows the control setting established, making the simulation replicable.

Results

In this section, the main results are reported. Overall, the wind power within the context analysed is relatively low. However, findings point out how the form and orientation of the buildings and their urban asset interact with the cyclical environmental variable. They make evidence that no structural relationships between the cyclical environmental variable and the built environment emerge, in this case. Results are presented in relation to the interaction between the three case studies analysed and the three dominant wind-directions (i.e., North, South, and South-East, with a frequency of 20, 1%, 9, 7% and 7, 5%, respectively) across the heating period (i.e., from November to April), as reported in the prior section. The next sections present the indexes calculation (Wind form
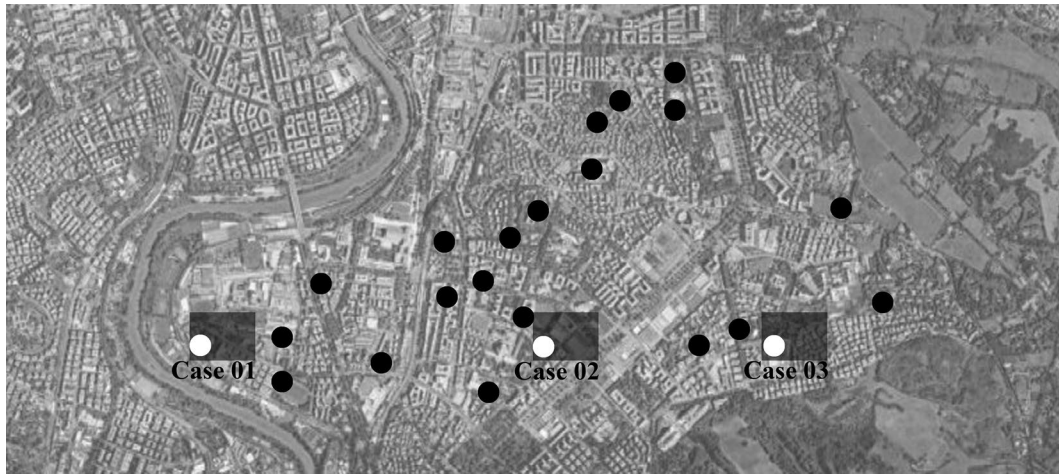
Fig. 2 Distribution of school buildings within the District: selection of the case studies
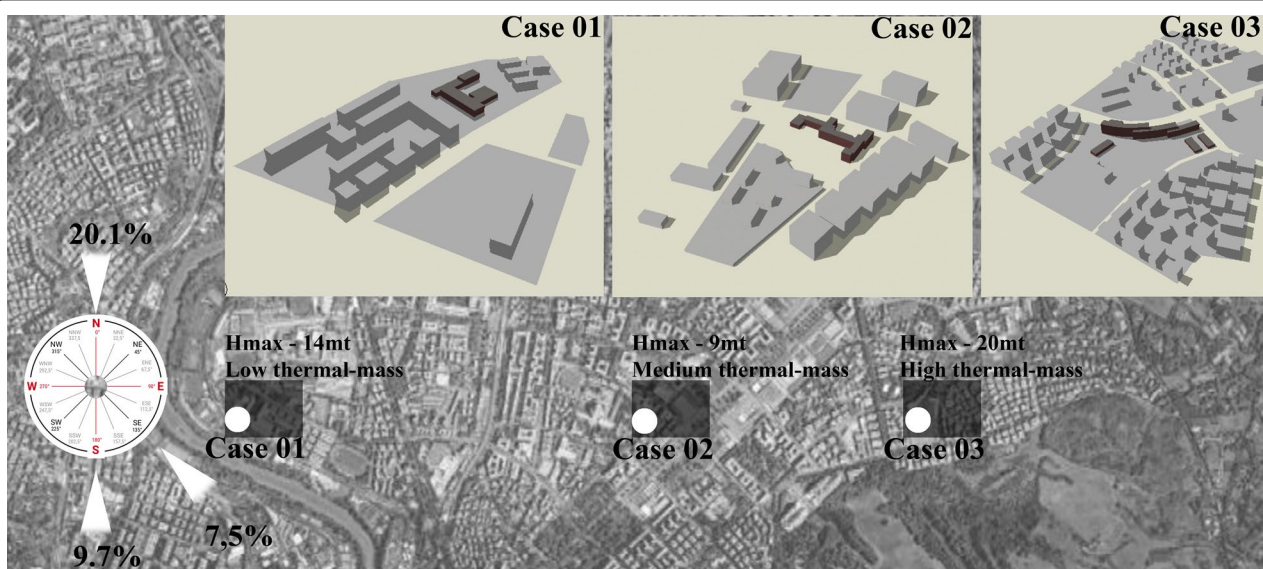
Table 1 CFD control setting panel: values adopted for the simulation

Turbulance model	K-e
Discetization scheme	Upwind
Max number of outer interaction	5000
Cell monitor	x-velocity
Residual display	x, y, z and K-e
Inner Interactions (x, y, z and K-e)	3
False time step (x, y, z and K-e)	0.2
Termination residual (x, y, z and K-e)	10^{-5}
Viscosity relaxation factor	1

index, $F_{w>0}$; Wind thermal-loss index ($P_{w>2}$); and Wind Energy Production index, $A_{w>5}$) and their comparison. Finally, a section dedicated to the reliability of the results is also presented.

Indexes calculation and comparison

Figure 4 shows positive values concerning the range of wind pressure, pointing out the main criticalities. It shows that winter wind exposure's most critical condition occurs during the highest winter wind-direction frequency (i.e., 21, 1%). The $A_{w>5}$ index was calculated for this condition, and the value was integrated into the

Fig. 3 Case studies features: urban patterns, building morphologies and wind-data

Wind-direction:N
Frequency: 21.1%

Wind-direction:S
Frequency: 9.7%

Wind-direction:SE
Frequency: 7.5%

Case 01

$F_1 = 3258 m^2$
$F_2 = 1052 m^2$
$F_{w>0} = 0.32$

Case 02

$F_1 = 6115 m^2$
$F_2 = 777 m^2$
$F_{w>0} = 0.12$

Case 03

$F_1 = 6558 m^2$
$F_2 = 1891 m^2$
$F_{w>0} = 0.28$

Fig. 4 Wind form index ($F_{w>0}$). Comparative 3D critical building areas
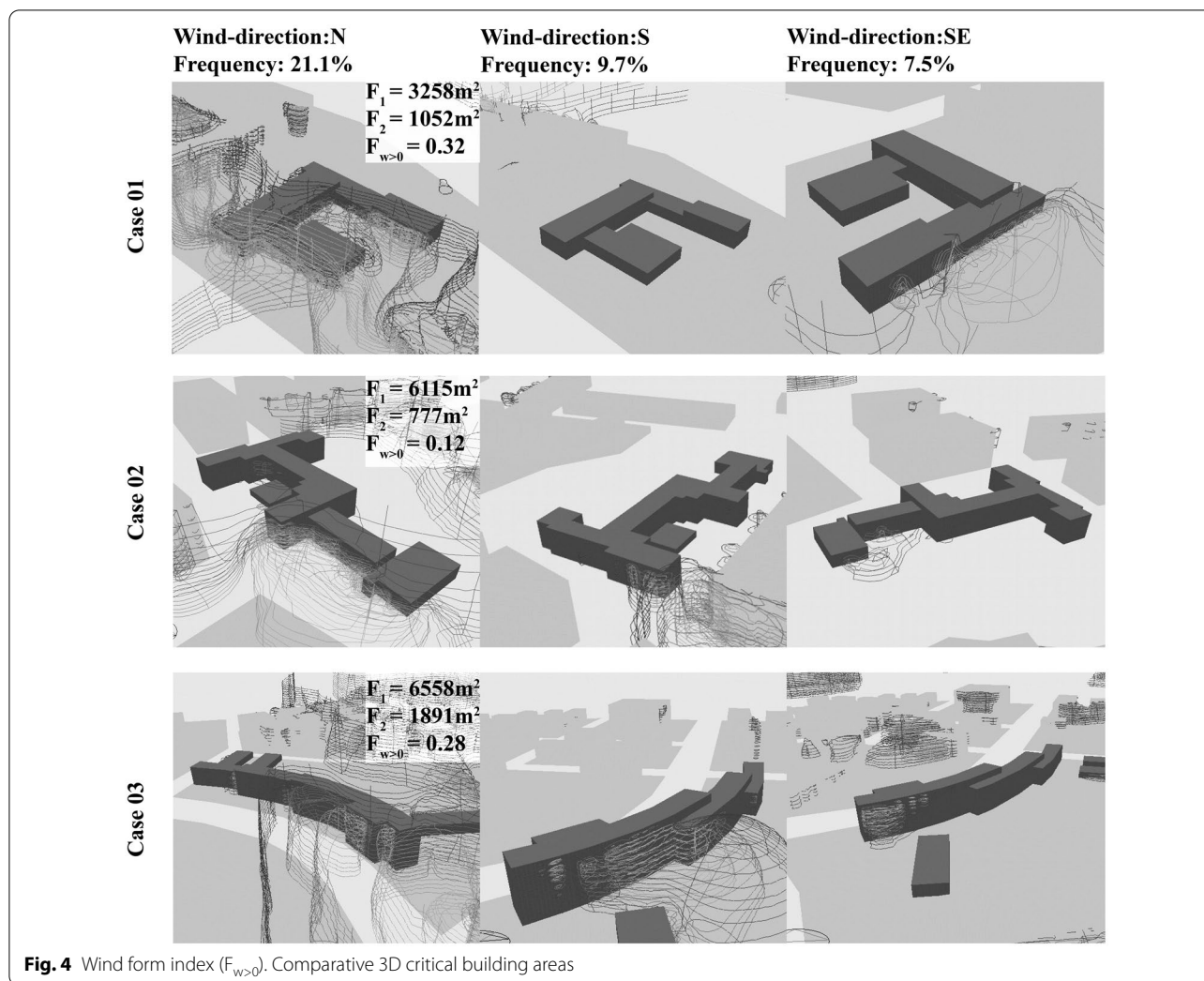
figure. Comparing the three cases, it is evident that the worst condition affects Case no. 1. The results are in line with the expectation since Case no. 1 is placed within the urban context with lower density. Case no. 2 is well protected from the dominant winter wind, and additional considerations can be done in this case. Indeed, 3D visualisation allows to observing the zone under stress. In this case, for example, the wind impacts the volume containing the gym and corridors, showing a very good condition. Nevertheless, it emerges as an occasional condition. Case no. 3 shows wind exposure highly influenced by the urban surrounding. In this case, findings point out that two opposite façades can be under positive wind pressure concerning the wind direction variation. Based on the current level of information, the façade under primary wind frequency should be prioritised. However, in order to establish an appropriate priority, additional LoI is needed. This, for example, could concern the activities as well as the glass-ratio of the exposed façades. The $A_{w>5}$

index and its visualisation are handy to assess the potentiality of wind strategies such as cross-ventilation and stack-effect.

Figure 5 shows the calculation related to the $P_{w>2}$ and $A_{w>5}$. It points out the building perimeter under critical conditions in terms of potential thermal losses (marked in red). Furthermore, it displays potential areas for micro-wind integration (areas marked with red lines). The figure includes all relevant information as described in "Methods" Section. The potential wind impact on building thermal losses is not significant at the current LoI. With regard to the $A_{w>5}$ index, results are not in line with the expectation. It was expected that Case no. 1, as the highest building, showed the highest opportunity to integrate RES based on micro-wind; instead, the highest opportunity belongs to Case no. 3. This condition is related to the influence of the urban surrounding.

Figure 6 compares the index values, pointing out what index is under the main criticalities for each building

Fig. 5 Wind thermal-loss index ($P_{w>2}$) and wind energy production ($A_{w>5}$)

Fig. 6 Indexes comparison
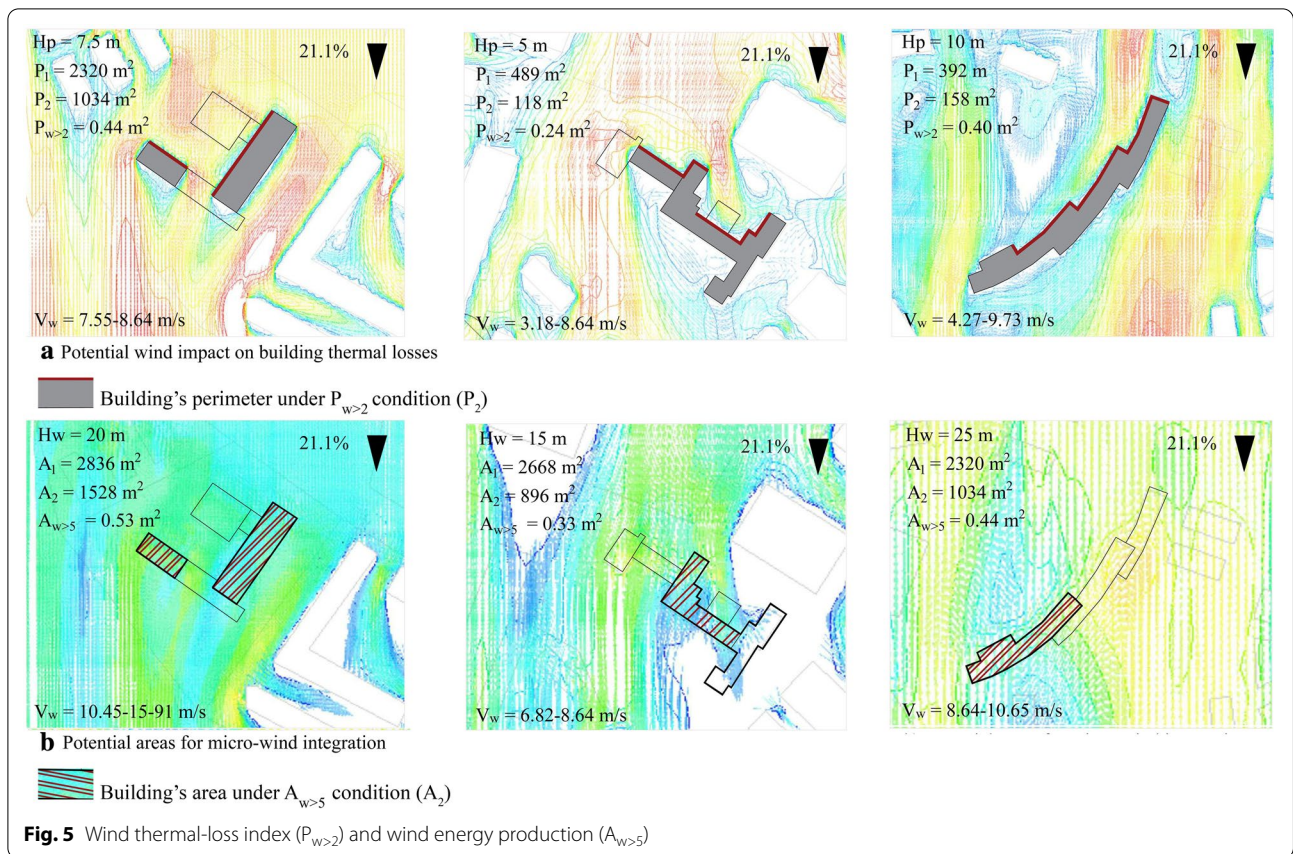
analysed. Based on this observation, it is possible to establish what type of additional data is needed to plan appropriate strategies. Results are in line with the expectation, pointing out that wind does not significantly impact. This does not mean that wind can be ignored, but only that, under this circumstance, increasing insulation based on wind winter exposed façades, for example, does not imply a relevant advantage in terms of thermal-losses. By contrast, if the results had shown higher values, the procedure would have identified key areas to operate, obtaining the most significant benefits. Similarly, the energy production from micro-wind, which does not appear as strategically relevant herein. The procedure adopted shows the hierarchy among the three cases, returning an image to prioritise retrofitting intervention at building and urban scale.
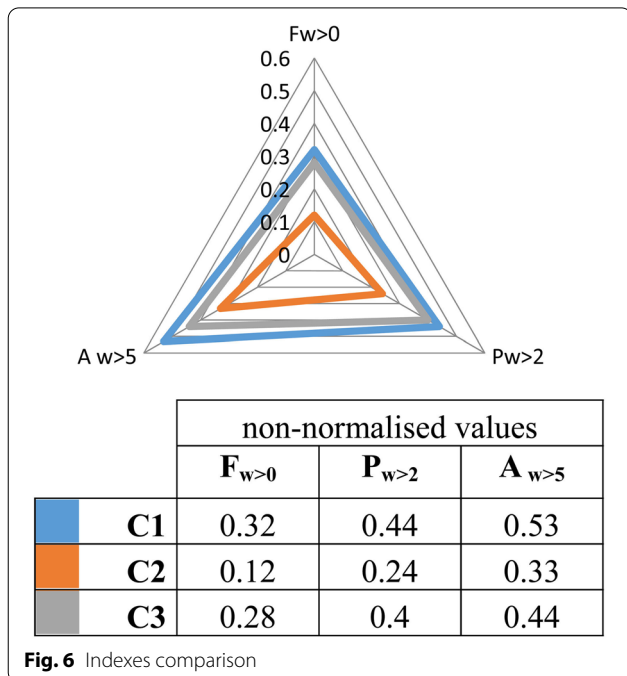
Reliability of results

Going into details, the urban surrounding of Case no. 1 is characterised by the following range of the wind-pressure: from − 180 Pa to108.49 Pa; from − 133.98 Pa to 100.94 Pa; and, from − 190.81 to 135.53 Pa about North, South-East and South wind-direction, respectively (Fig. 7). In this case, the building shows an inverse
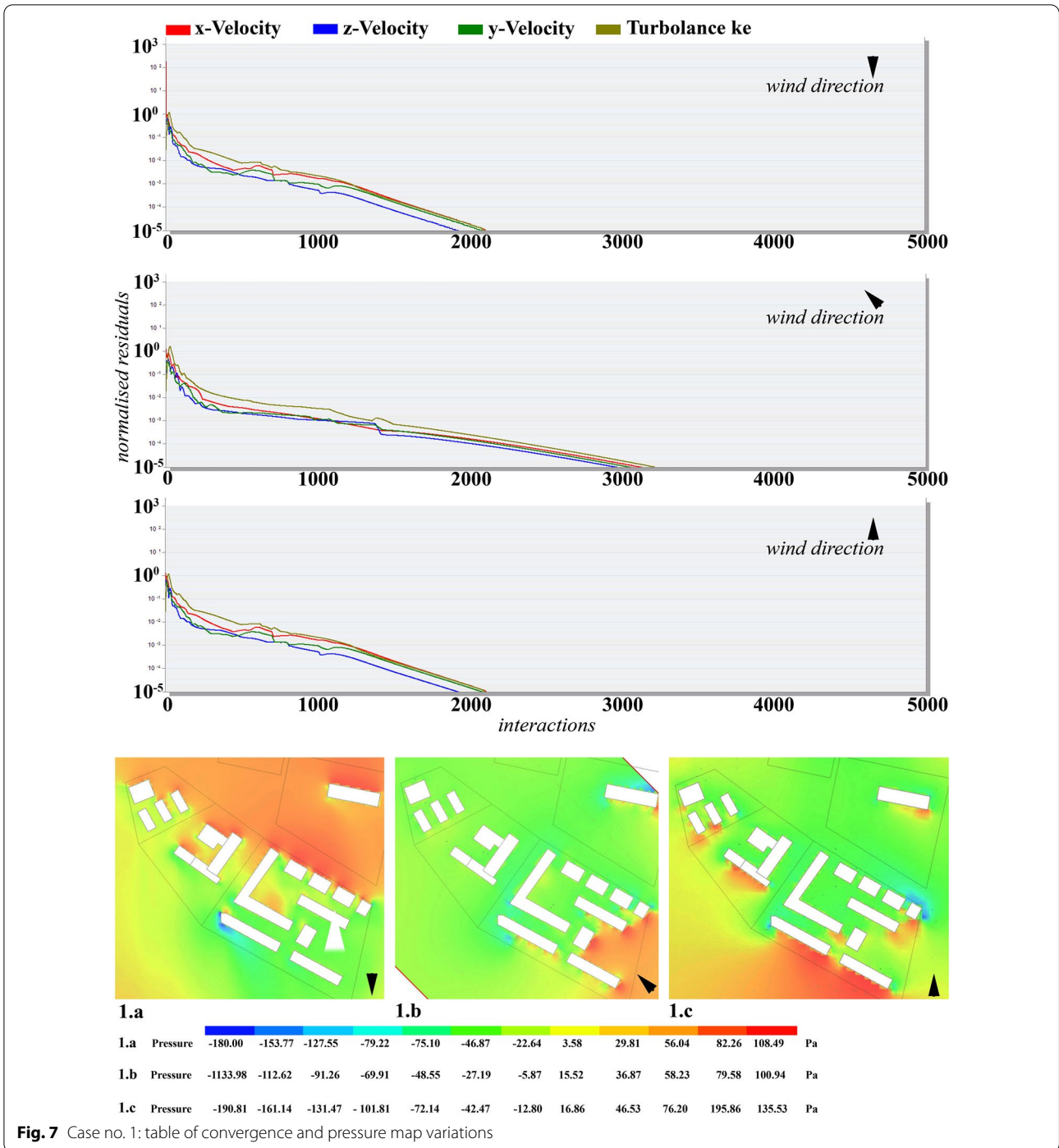
x-Velocity ■ **z-Velocity** ■ **y-Velocity** ■ **Turbolance ke**

wind direction

wind direction

wind direction

normalised residuals

interactions

1.a **1.b** **1.c**

		-180.00	-153.77	-127.55	-79.22	-75.10	-46.87	-22.64	3.58	29.81	56.04	82.26	108.49	Pa
1.a	Pressure	-180.00	-153.77	-127.55	-79.22	-75.10	-46.87	-22.64	3.58	29.81	56.04	82.26	108.49	Pa
1.b	Pressure	-1133.98	-112.62	-91.26	-69.91	-48.55	-27.19	-5.87	15.52	36.87	58.23	79.58	100.94	Pa
1.c	Pressure	-190.81	-161.14	-131.47	- 101.81	-72.14	-42.47	-12.80	16.86	46.53	76.20	195.86	135.53	Pa

Fig. 7 Case no. 1: table of convergence and pressure map variations

condition of pressure concerning North and South wind direction's impact. The former implies a positive pressure on the North façade and negative pressure on the South one. The latter vice versa. Significantly different is the case on South-East wind direction. In this case, the building's long block placed on the SE quadrant creates a long wave of wind-shadow. In addition, the "c" cavity, which is reversed with respect to the wind direction exacerbates the negative pressure. Finally, the south wind direction shows a high impact on the south-west façade due to the absence of obstacles (i.e., the façade is orientated towards the river). Convergence was achieved for all wind exposure conditions. For the SE direction the convergence was achieved at different range with respect to N and

S exposure. It is in line with the expectation. Indeed, from the computational point of view, N and S are quite similar.

As concern the urban area related to Case no. 2, the range of the wind-pressure is distributed as follows: from − 131.54 to 115 Pa, from − 113.70 to 161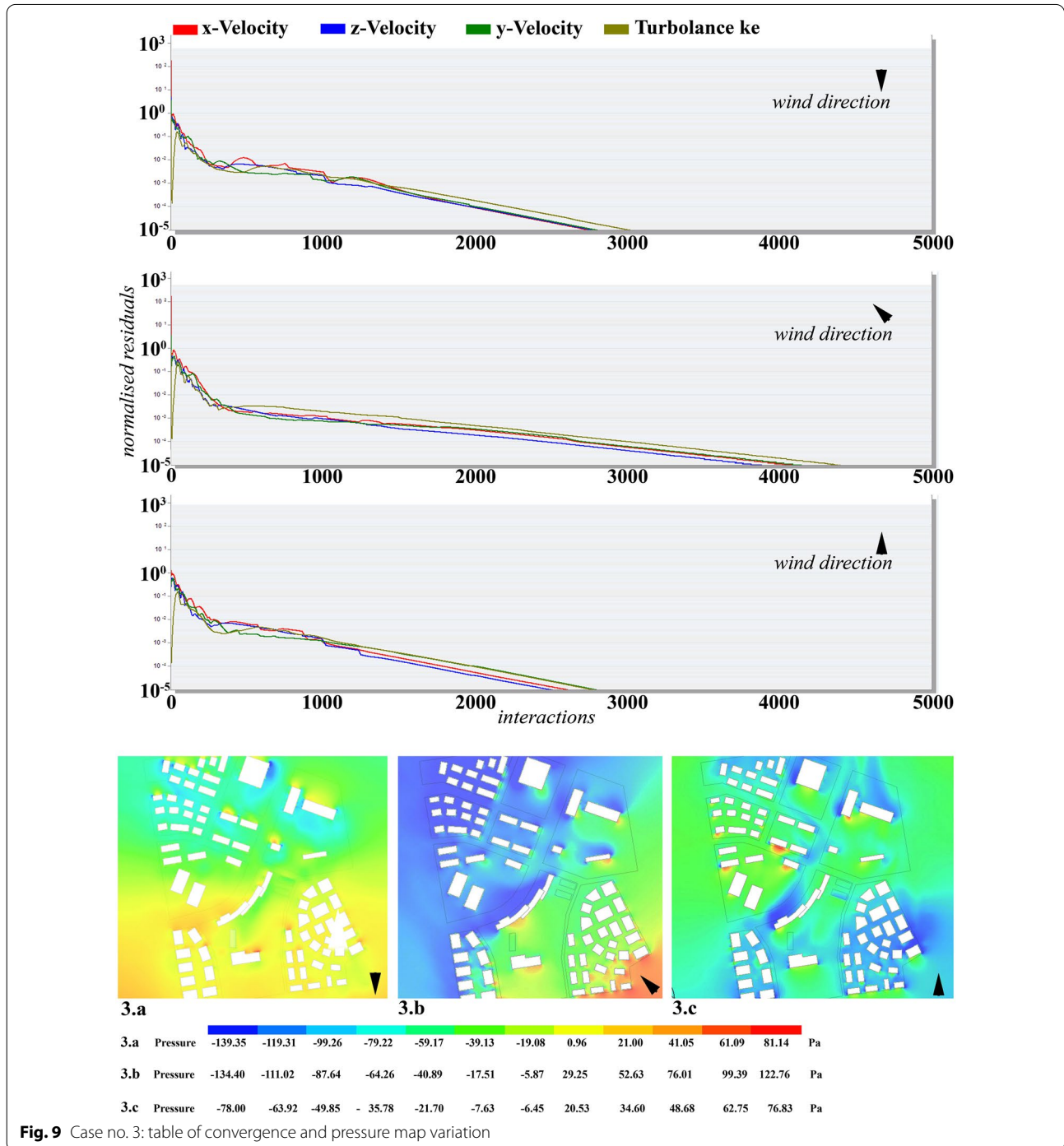.05 Pa, and from − 139 to 142.47 Pa about North, South-East and South wind-direction, respectively (Fig. 8). Focusing on the buildings, the block located at the North-East quadrant generates a wind-shadow, which determines an inversion of pressure on the involved building façade. In contrast, the other part of the building with the same exposure is under positive pressure (84.18–115 Pa) due to the absence of obstacles. About other wind directions,

Fig. 8 Case no. 2: table of convergence and pressure map variations
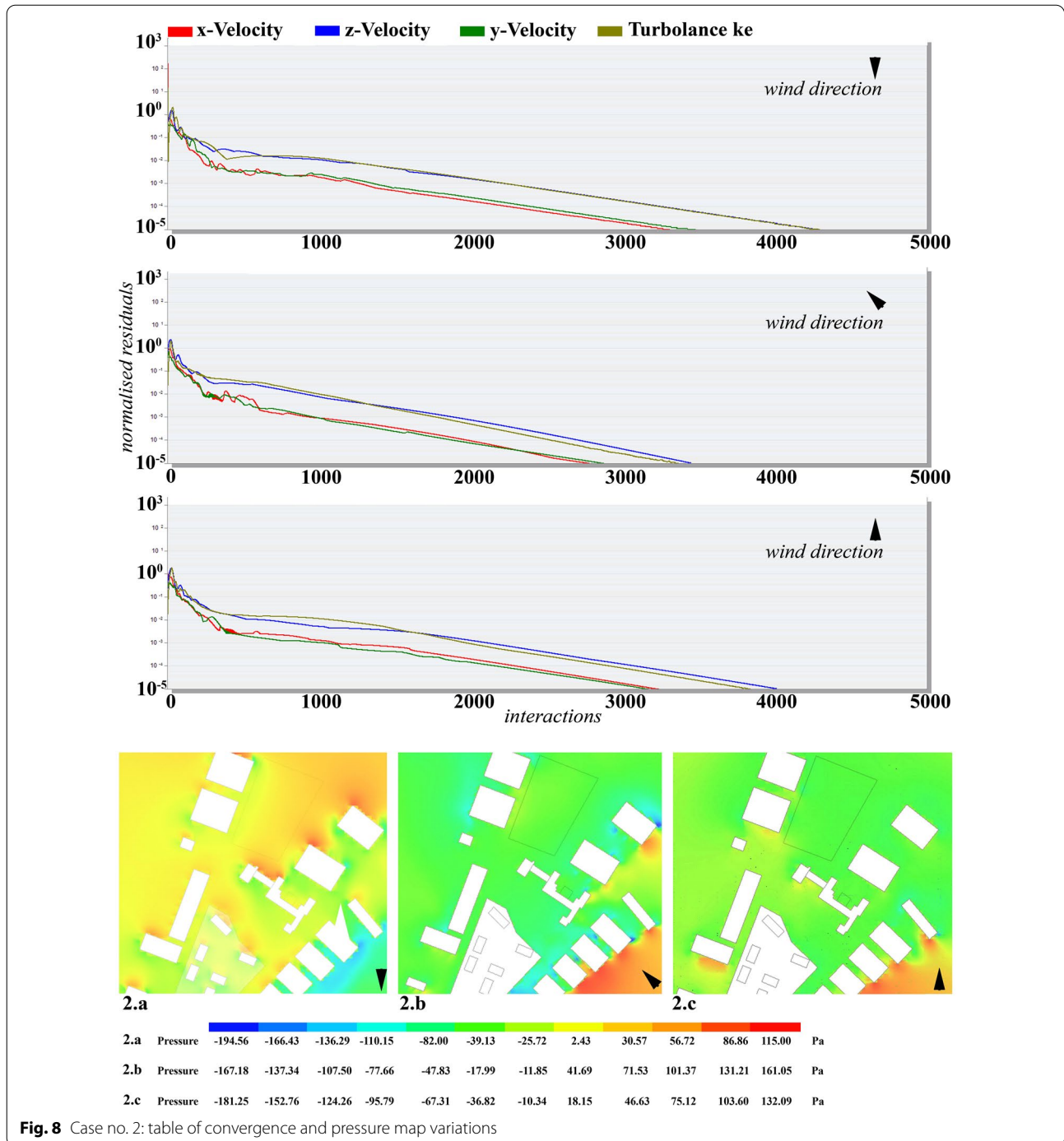
the situation completely changes. For instance, regarding the South-East wind-direction, the building is enclosed in a negative pressure areal; similarly the case of South wind-direction, although a partial inversion of pressure is shown by the south façade of the west part of the building. Convergence was achieved for all wind exposure conditions. A soft discrepancy in Z and K-E with respect to x and y was revealed. However, the convergence was achieved within a similar range.

Finally, the range of the wind pressure related to the area of Case no. 3 is distributed as follows: from − 139 to 81.14 Pa, from − 134.40 to 122 Pa, and from − 78 to 76.83 Pa about North, South-East and South wind direction, respectively (Fig. 9). Analysing the impact on

3.a	Pressure	-139.35	-119.31	-99.26	-79.22	-59.17	-39.13	-19.08	0.96	21.00	41.05	61.09	81.14	Pa
3.b	Pressure	-134.40	-111.02	-87.64	-64.26	-40.89	-17.51	-5.87	29.25	52.63	76.01	99.39	122.76	Pa
3.c	Pressure	-78.00	-63.92	-49.85	- 35.78	-21.70	-7.63	-6.45	20.53	34.60	48.68	62.75	76.83	Pa

Fig. 9 Case no. 3: table of convergence and pressure map variation

the building, it emerges that the north façade is under positive pressure. In contrast, the south facade is under prevalent negative pressure. However, this condition is not uniform around the building. This is due to the urban pattern, the form of the building and its orientation. The former does not present relevant obstacle in the north quadrant. The latter implies a large wind shadow in the south quadrant and a variation of the wind angle impact. Such a wind angle impact determines the highest level of positive pressure (19.63 Pa) on the southern part of the building. The above-described condition partially changes in the case of SE wind direction. Under this circumstance, the positive pressure is attenuated by the block of buildings, which lies on the SE quadrant. Convergence was achieved for all wind-exposure conditions. No discrepancy in x, y, z and K-E was revealed. Likely the Case no. 1, the SE exposure appears to be different from N and S due to a different urban pattern.

Discussion: towards PEB configuration

Positive Energy Block (PEBs) is emerging as new paradigms to transform cities into low carbon cities. According to a vast literature (Knowles 2003; Ratti and Claudel 2012; Butera 2013; Sibilla and Kurul 2018) the integration of the cyclical environmental variables is a fundamental approach to reducing the energy demand and contrasting the homologation and vulnerability of fossil-based fuel settlements. Therefore, how to synchronise energy, spatial and environmental features of future settlements is a new dilemma. This study has developed an environmental design approach focused on using of wind analysis to orient strategic design solutions for PEBs.

Specifically, our results emphasise the opportunity to improve wind impacts, working on specific parts of a building and its surroundings. Thus, the approach proposed is a way to optimise benefits, taking into account the constant lack of public resources that makes complex radical transformations. Consequently, this approach may be considered straightforward to support decision-makers to plan the agenda to transform buildings into components of PEBs, through a sequence of organised steps.

Our results are in line with prior studies (Straw et al. 2000; Dimoudi et al. 2013; Xie et al. 2020), which have emphasised the importance of visualising the impact of cyclical variation of the wind to support decision-making processes for improving both the energy and environmental qualities of existing and new buildings. However, none of them has finalised a 3D visualisation to orient strategies and optimise resources concerning the scenario of PEBs. Here, the novelty of this work lies.

So far, PEB has been a topic mainly focused on engineering systems, energy performance and business models, as reported in the background section. In contrast, this study considers the PEB paradigm as an opportunity to rethink urban and buildings components as a whole, integrating the cyclical environmental variables in a multi-perspective analysis. In this work, we operated within a logic of aggregation of buildings, identifying weaknesses and opportunities for each building and planning strategic solutions accordingly.

This was done in agreement with other works (Arens and Williams 1977; Axaopoulos et al. 2015; O'Sullivan and Kolokotroni 2017), asserting that qualitative analysis supported by CFD simulation can be used to prioritise objectives in an early design stage, pointing out straightness and weakness concerning specific designing choices. Therefore, developing a platform in which the cyclical environmental variables can be integrated emerges as a strategic priority. This type of platform can synchronise building transformations, considering the potential role of each building as a component of the future energy infrastructure. By doing so, wind and sun can be integrated into the management of urban and building transformations as structural factors rather than occasional ones.

As stressed in the introduction, a PEB involves at least three buildings, and their gradual transformation is a crucial aspect of the low carbon transition. Thus, as a starting point, it is necessary to identify buildings with specific pre-requisites. In this regard, PEB organisation is related to three main aspects: (1) the selection of buildings that must be aggregated; (2) the energy optimisation of the aggregated buildings; and the RES integration potentialities. The three indexes elaborated herein are offered to better understand how wind can contribute to the aspects above mentioned.

The first index ($F_{w>0}$) returns a scenario based on building and urban wind exposure. In contrast with the sun analysis, the best orientation is difficult to be visualised in the case of wind. Our findings show the high level of randomness between urban pattern, building forms and the cyclical variation of the wind. Therefore, the synchronised view proposed, which connects the three cases, allows a decision-maker to prioritise strategic intervention. A practical example about how to use the results of this qualitative analyse emerges from Case no. 1. In such a case, an urban regeneration strategy focused on the riverbank's vegetation to contrast thermal losses in winter (and solar overheating in summer) should be prioritised. This is a typical example of a holistic approach, in which the introduction of cyclical environmental variables may be used to regenerate the whole system. On the other hand, Case no. 2 and 3 are placed in consolidated parts of the city, and other strategies are required to improve their wind exposures.

However, other urban areas may present more flexible urban structures.

The second index puts in relation the wind impact with the thermal losses, thus with the construction and morphological features of a building. According to Arens and Williams ([1977]) and O'Sullivan and Kolokotroni ([2017]), this can be a relevant factor under specific building construction conditions. For example, the impact is high for buildings characterised by glass facades, especially those built between 1970 and 1990, with low energy performance. This construction typology is relatively diffuse in Rome, although for office buildings and not for school buildings. What is important from the methodological perspective is that the case study analysed suggests how to associate the wind information to the LoD. For example, once the parts of a building under major criticalities have been individuated, additional LoI can be established. For example, the data related to the glass-ratio of façades and their airtight performance becomes essential to quantify the impact. In other words, the index suggests a hierarchical process to improve the energy efficiency of a stock of buildings, upgrading the thermal performance of specific part of the building envelope. This is also essential to set the renewable plan system at the minimum. However, a PEB scenario composed of these three buildings can be implemented through different configurations. Thus, ideally, one building is active while two of them are NZEBs. Alternatively, a configuration could be one positive, one NZEB and one standard (this also depends on the space for RES available). Nevertheless, achieving the status of NZEB is not easy, especially if the environmental components are ignored. In this regard, our findings based on the CFD technique may be used as a predictive tool to save time and cost. In line with (Good et al. [2008]), our findings can help elaborate several "what-if" scenarios, including a set of hard and soft building transformation strategies. Thus, the 3D platform is offered as a tool to observe some aspects which would be challenging to identify. These aspects can be used to orient the retrofit of existing buildings, in particular for those where the wind has significant negative impacts.

The third indicator concerns energy production. From the point of view of energy production, the wind condition in Rome is not performative. The frequency of 20.1% and wind speed often under 5 m/s are not considered optimal conditions. This is especially true if we are going to compare micro-wind performance with PV one under such conditions. However, focusing on the index significance rather than its numerical value related to this case study, our findings may be helpful to assess areas where potential combined technologies are admissible. Additionally, another factor must be considered: technological innovations in the industrial sector of advanced sustainable systems (e.g., micro-wind turbine). Until recently, the application of micro-wind turbines within an urban environment was considered unworkable. Nowadays, the application of this technology continues to be considered hard due to a set of technical issues as stressed by literature (Marini et al. [2017]; Mamia and Appelbaum [2016]; Waewsak et al. [2017]). However, it is expected that their applications will be extended together with the diffusion of sensors and real-time monitoring platform, reducing the level of uncertainties. This, for example, can resolve one of the barriers concerning wind technology applications, which are based on weather stations often located very far from the place of installation.

Therefore, the considerations proposed in this study has been built upon a scenario where the management of public assets will be even more based on ICT technologies and tools characterised by parametric information (e.g., BIM platform) and real-time information (e.g., sensor devices). Figure [10] suggests the potential benefit of extending the approach to all the school buildings belonging to the district in Rome, allowing the Municipality of Rome to have a "big picture" to plan appropriate strategies. This study has stressed that the level of information adopted herein can be expanded and improved. This work has opted for a 3D visualisation, allowing users to recognise the LoI on which the simulation was based. The need to make accessible this information is currently a challenge. Indeed, decision-makers cannot optimise an environmental design solution without a tool that simultaneously compares different urban patterns. Consequently, the approach proposed can significantly impact future urban pattern organisation, especially in the case of public buildings as pilot projects. The organisation of PEBs based on public buildings may be promoted to operationalise the low carbon transition at the local level.

Conclusions

This study developed an environmental design approach focused on using wind analysis at scale to orient strategic design solutions for PEBs. Based on the assumption that the transition towards PEBs should be an opportunity to redefine the rules to organise the built environment structure, a sequence of structured wind simulation analysis was carried out. This sequence was offered as a preliminary procedure to synchronise wind strategies at scale. In details, this study carried out three integrated indexes, $F_{w>0}$, $P_{w>2}$ and $A_{w>5}$, to assess the pre-requisites of buildings to act as components of a PEB, with a particular focus on wind impacts in terms of form, exposure and energy production, respectively. These indexes were designed to be transferred into an integrated platform, providing a significant contribution in managing the PEB transformation
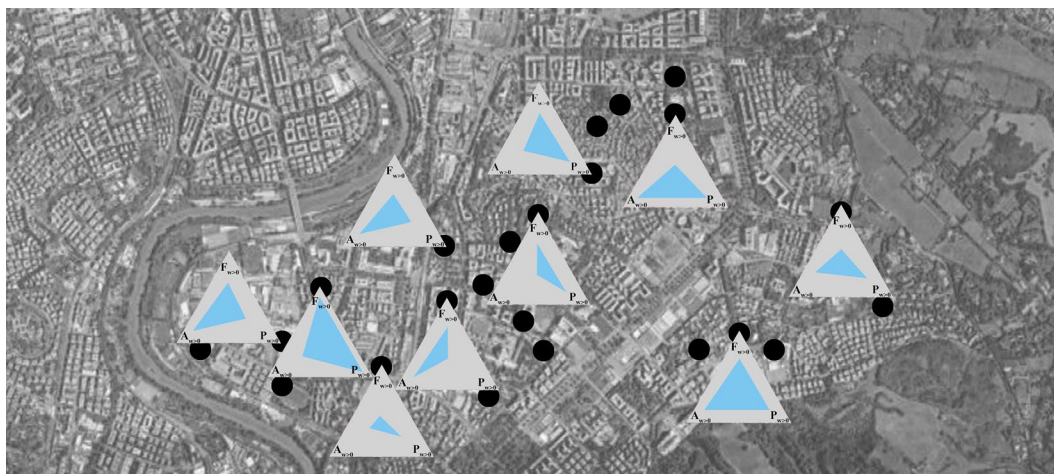
Fig. 10 The procedure applied at scale

process. Precisely, decision-makers benefits to planning the agenda to transform buildings in components of PEBs was stressed.

This study has several limitations, especially concerning the level of information. For example, wind data comes from the nearest meteorological station, usually located near airports. However, this information can significantly differ from the urban context due to the built environment's impact. Therefore, considering the increasing dissemination of sensors within the urban structure and buildings, it is expected that this integration could bring significant advancement in the environmental design strategies optimisation. In this regard, further research focused on a Digital-Twin platform for PEBs organisation is a possible solution. While platforms for information sharing through web-based GIS are being consolidated; a Digital-Twin-platform for PEBs is a new direction that promotes further integration among stakeholders of Architecture, Construction, Engineering and Planning sectors. In the future, this type of process-oriented platform could be integrated by remote sensing, promoting additional inputs from the construction industry for the application of sensors to accurately measure local environmental conditions (e.g., wind velocity and pressure).

In conclusion, this study has been presented as a preliminary step towards an advanced platform integrating cyclical environmental variables supported by real-time monitoring to support the gradual step towards using integrated simulation tools to put PEBs into practice at the local level.

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