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Review

Leveraging the Opportunities of Wind for Cities through Urban Planning and Design: A PRISMA Review

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Abstract: Wind has been utilized for passive ventilation and mechanical power since antiquity. As an abundant renewable resource, today, wind is increasingly seen as a critical resource to help tackle issues associated with rapid urbanization and climate adaptation and mitigation, such as improving thermal comfort, providing clean energy, improving air quality, and reducing carbon emissions. Despite the growing importance of wind as an invaluable resource for cities, wind in the context of urban planning and design is a relatively understudied area of research. This study aims to explore the means by which cities that can benefit from wind and ways urban planning and design can help deliver these benefits. The study adopts a systematic literature review methodological approach. The findings disclosed that: (a) improving urban wind environment via sound urban planning and design may enhance urban ventilation and energy performance; (b) better urban ventilation and energy performance enable cities to become climate positive or net zero and relieve the urgent climate crisis; (c) wind sensitive urban design is an emerging research area critical to harvest the benefits of wind for cities. This study offers a novel conceptual framework and research directions for wind sensitive urban design and informs urban planning, design policy and practices.

Keywords: carbon neutral city; carbon positive city; climate change; nature-based urban design; sustainability; urban heat island; urban planning and design; urban ventilation; urban wind energy; wind sensitive urban design (WiSUD)

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1. Introduction

The world's urban population is experiencing exponential growth. Current estimates anticipate that the global population will expand by 25% by 2050, with an extra 2.5 billion people moving to cities in the following three decades [1]. As climate change and other stressors increase, the need for a more sustainable and resilient built environment becomes increasingly important [2–4] Cities need to be designed to support strategic resource management by integrating sustainable resource utilization to meet contemporary pressures of accelerating urbanization, limited resource availability, and changing climate—particularly by benefiting from the technology offerings and their sustainable practices [5–7].

The notion of harnessing the kinetic energy of wind and transforming it into usable mechanical labor was first envisioned in antiquity, and wind energy is the earliest source of energy that has been used by humans [8]. Furthermore, wind also serves as a natural resource that ventilates buildings and provides a cooling effect [9]. Yet, to increase the applicability of wind research to practical solutions for a sustainable and resilient city, there needs to be a translation of the technical and quantitative information in a way that can inform urban development strategies. However, past efforts have either been scattered across different areas or did not consider detailed urban implications [10]. Further research is needed to advance the translation of wind engineering research into urban design and planning processes.

In terms of the background and significance of such need, a systematic literature review can provide insights into current research on leveraging and managing the potential of wind in cities. So far, several different systematic reviews on urban wind applications have been published in various academic disciplines over time. For instance, Blocken and Carmeliet [11] examined pedestrians' wind comfort from a building physics perspective and illustrated this with four practical examples. However, the study considers wind as a potential hazard rather than useful asset. The widespread interests in urban sustainability and energy transition have produced an increasing number of academic papers on leveraging the potential of wind. Likewise, Stathopoulos et al. [12] reviewed developments in urban wind energy. Their review highlighted engineering and technical issues associated with urban wind turbine technologies, and the difficulties of assessing urban wind energy potentials. Palusci and Cecere [13] produced a systematic review on the topic of urban ventilation in compact cities, where they stressed the importance of embedding a multidisciplinary methodology into urban management and planning processes.

In terms of problem definition, despite the growing attempts at utilizing renewable resources—that also includes wind—for making our cities more sustainable and livable, there is limited and scattered knowledge on effective and efficient ways to leverage the opportunities of wind for cities through urban planning and design mechanisms [14]. Given the presumption that urban planning and design can effectively integrate renewable sources in the urban environment, there is a critical need to develop a comprehensive conceptual framework in our existing and future cities. In recent years a new planning and design concept has emerged, i.e., wind sensitive urban design (WiSUD) [15]. However, a review of the literature and practice shows that the current practice of WiSUD is highly limited.

In terms of motivation and objectives, against the above backdrop, the aim of this study is to investigate how cities may benefit from wind and how urban planning and design can aid in achieving these advantages. To achieve this, the paper adopts a systematic literature review methodological approach. The findings offer conceptual framework and prospective research directions for wind sensitive urban design and informs urban planning, design policy, and practices. The main objective is to synthesize different aspects of urban wind research and propose a conceptual framework that can actuate the benefits of wind in organizing, planning, and designing our cities.

Following this background, the rest of the paper is structured as follows. Section 2 details the methodological approach. Section 3 presents the results of the study. Section 4 discusses the findings, proposes a conceptual framework, and puts forward prospective research directions. Section 5 concludes the paper.

2. Materials and Methods

This study utilizes a systematic literature review method by employing the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) technique, consisting of four primary phases as explained by Moher et al. [16] and Cortese et al. [17]. This method includes identifying the relevant articles, screening, determining eligibility, and finally inclusion. A search of the literature was carried out in the first step, which was identification, using the two databases with the most peer-reviewed articles, i.e., Web of Science (WoS) and Scopus. The goal was to generate new insights into the current state of knowledge of wind as a useful resource in the urban context.

The research acknowledges the complexity and multidisciplinary nature of urban wind research, which includes fields such as computer science, engineering, and natural sciences. The research focus is on wind research with connection to urban development strategy. Therefore, the area of study concentrated on urban studies and social science to shortlist the records included in the dataset for analysis. Technical articles in the fields of engineering and natural sciences frequently provide novel methodologies and instruments for realizing the use of wind in urban environments. The literature in these subjects, on the other hand, tends to be rather theoretical and seldom addresses the topic's applicability within actual urban environments. In contrast, literature produced in the domains of urban studies and social science offers a more holistic perspective, including novel knowledge from empirical observation to detailed implications on city operations.

Criteria to identify relevant sources included: (a) journal papers that were peer-reviewed; (b) readily available online; and (c) written in English. The publishing date was purposefully kept open so that it considered the earliest documents that were accessible. The search was conducted with the following query string in May 2022: "wind OR gust OR breeze" AND "urban OR city OR cities" AND "planning OR design". By limiting the field of studies, Scopus and WoS provided 617 and 179 records, respectively. Following the elimination of duplicate records, the total number became 767.

The second stage consisted of focusing on the advantageous characteristics of wind that may be harnessed with urban development strategies. Papers that were completely unrelated to the goal of the study, as well as articles that covered the mitigation measures for the negative aspects of wind, such as wind hazards, were not included in the analysis. Table 1 summarizes the inclusionary and exclusionary criteria for the screening stage.

Table 1. Exclusion and inclusion criteria.

Primary Criteria		Secondary Criteria	
Inclusionary	**Exclusionary**	**Inclusionary**	**Exclusionary**
Academic journal	Duplicate records	Wind research relating to urban development strategies	Technical papers in engineering and natural sciences
Peer-reviewed	Books, chapters, conference papers	Relevance to research objective	Irrelevant to research objective
Full-text online Published in English	Industry/government reports		

For the third and fourth stages, to establish whether the selected records were relevant to the overall scope of the study, abstracts and titles of the sources were checked. Then, the number of articles was reduced to 101. Those articles were then read in full text. A further 31 articles were excluded from the pool. A supplementary document search in Google Scholar was also conducted because research shows WoS and Scopus tend to have a strong bias towards natural sciences and engineering in their content [18]. The search engine returned 35 additional articles, bringing the total number of articles to 105 (Figure 1). The full list of the selected articles is presented in Appendix A. Records were then processed and labelled following the guideline by Degirmenci et al. [19]. The documents were screened in Excel and were sorted into a concept matrix according to the subject matter, the research relevance, geographic scale, methodologies, and regions.

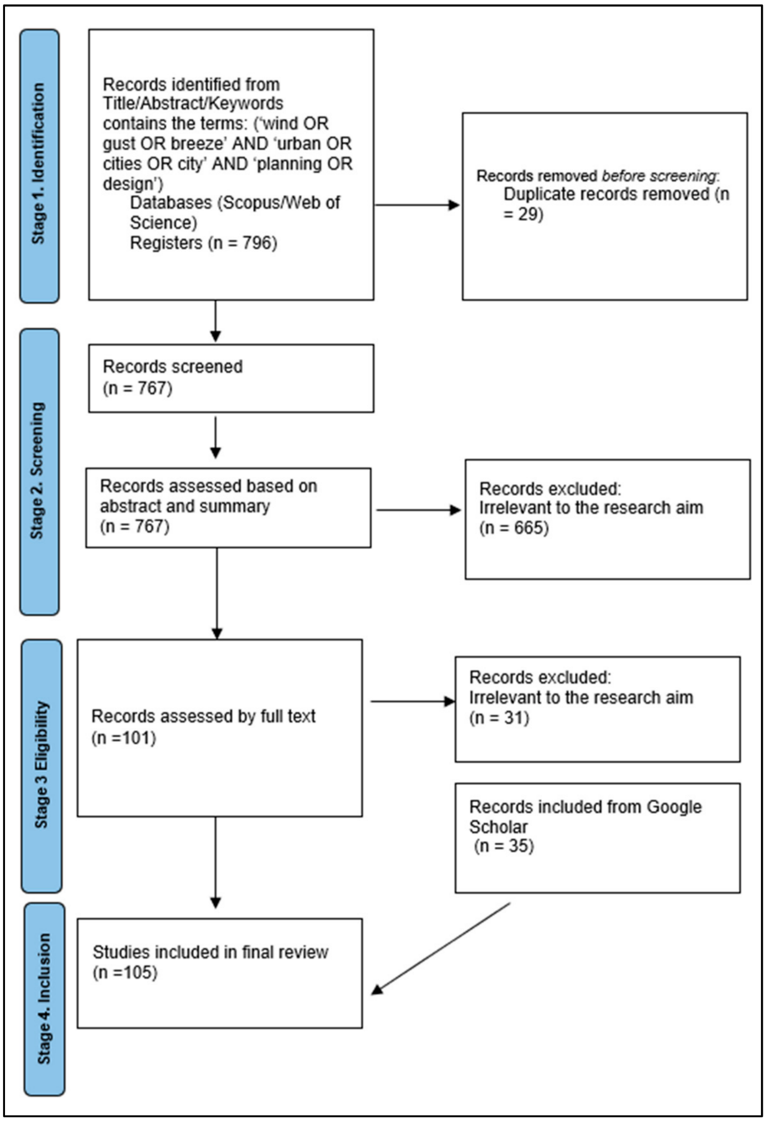

Figure 1. The literature review search strategy.

3. Results

3.1. General Observations

This review encompasses 105 different articles. The publication distribution by year and regions are illustrated in Figures 2 and 3. The earliest article was released in 2003; the number of sources has steadily increased since 2015, demonstrating researchers' growing interest in urban wind. About 70% of the articles are from the recent five years. This indicates that the findings are relatively current. Europe and East Asia are the leading study regions in terms of the number of publications, with 20 and 54, respectively. This demonstrates that academic institutions and researchers in these two locations have a significant interest in wind research. Due to the threat posed by climate change and the concerns surrounding the unpredictability of energy supply, it is probable that the issue of the importance of comprehending the urban wind environment is gaining a rising amount of attention in academic circles, mainly throughout East Asia and Europe.

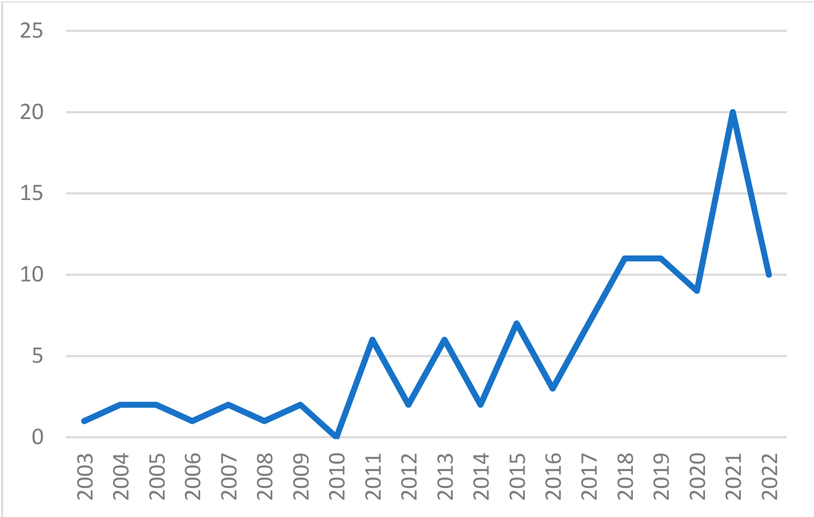

Figure 2. Publication distribution by year.

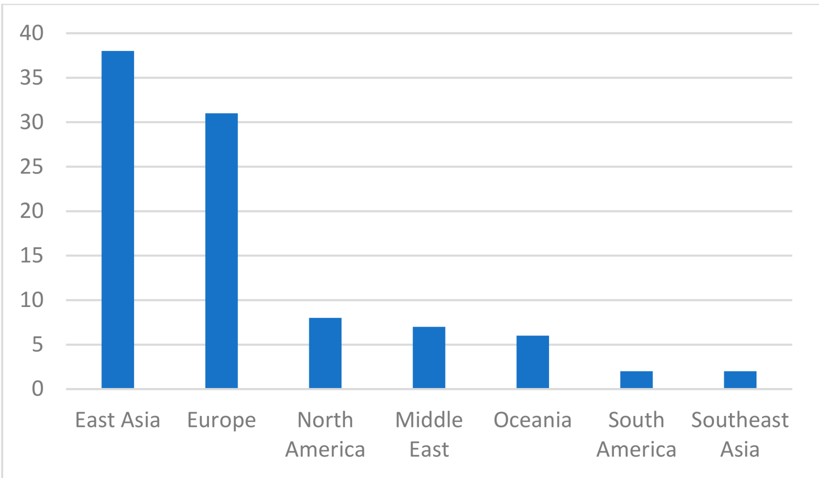

Figure 3. Publication distribution by region.

On the other hand, it is important to highlight the fact that wind research coming out of East Asia is gaining more and more prominence. From the 31 papers originating from East Asia, 28 were published by authors from this region after 2015. Researchers from East Asian countries such as China, Japan, and South Korea contributed the most, which is probably because the region has the highest urban development intensity compared to other regions of the world [20]. A possible justification for this occurrence is that East Asian cities, particularly Chinese cities, are increasingly confronted not only with difficulties related to energy sustainability, but also with the deterioration in the urban environment because of the rapid urbanization that has occurred over the course of the previous decade [21]. There is also an increasing number of relevant publications from regions other than Europe and East Asia. Papers from the Middle East (n = 7), Oceania (n = 6), and Southeast Asia (n = 2) were all published after 2015, which demonstrated the ubiquitous necessity of incorporating wind into urban development strategies. To tackle this complication, a simple keyword search was performed to identify the terms that appeared most frequently in the list of selected articles. The most common search terms returned were “ventilation” and “wind turbine”, and the results may be divided into three broad categories: “Wind in the Context of Urban Ventilation”, “Wind in the Context of Urban Energy”, and “Wind in the Context of Urban Planning and Design”. Based on the review, a mind map of urban wind research was created and is illustrated in Figure 4.

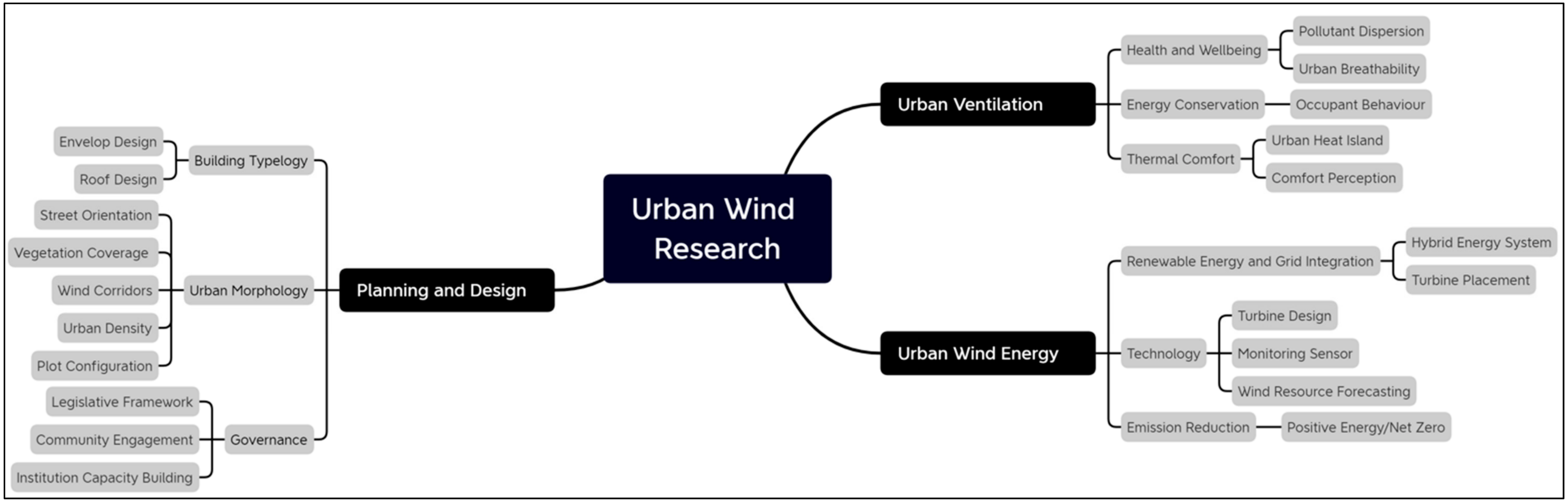

Figure 4. Mind map of urban wind research.

3.2. Wind in the Context of Urban Ventilation

In comparison to rural regions, urban areas have a less favorable wind condition (He et al., 2019). Air pollution and excessive heating are two primary problems that may result from inadequate wind movement [22]. The negative consequences of unfavorable wind conditions can be alleviated by good ventilation. Urban ventilation is referred to as the capacity of cities to introduce fresh air inside its tissues while also dispersing pollutants and heat within their canyons [23]. According to the literature review findings, urban ventilation can contribute to the satisfaction of requirements for thermal comfort, the conservation of building energy, and the promotion of health and wellbeing among urban dwellers. The results acquired in one location cannot be immediately applicable to other locations with different climates; for instance, high wind penetration is less desirable in cooler climates but more favorable in warm climates. This section of the review is not intended to be exhaustive on the quantitative details of various climatical parameters such as wind speed, temperature, and radiation intensity. Rather, the objective of this part is to provide a succinct summary of the rationale and considerations of optimizing ventilation in the contemporary urban context. The articles in this section provided extensive evidence and inference regarding the purported benefits.

3.2.1. Thermal Comfort

Urban ventilation's capacity to lower the urban heat island (UHI) effect is the most frequently cited benefit [14,24,25]. The impacts of UHI may have a detrimental influence on the thermal comfort of outdoor activities due to the increased temperature [26]. Better ventilation and wind penetration are especially significant in cities located in regions with warmer climates because they enhance outdoor thermal comfort by accelerating heat exchange between the population and the environment [27]. Empirical research indicates that UHI occurrences can be greatly mitigated when wind speeds are beyond a particular threshold [28]. Consequently, ventilation effectiveness is frequently evaluated based on wind velocity and the resulting change in the external temperature environment [6,29,30].

Other specific aspects must also be addressed when enhancing thermal comfort through urban ventilation, according to studies. For example, in addition to wind speed, relative humidity also impacts thermal comfort [26,31]. This is especially pertinent in coastal regions that often receive a sea breeze. As a sea breeze brings moisture, multiple studies have documented a sea breeze's ability to reduce the impacts of UHI to various extents [15,32]. Wind flow direction characteristics are as significant as wind velocity when developing an effective ventilation system for cities [33,34]. It is imperative that structures do not obstruct the prevailing wind, since it has been observed that in coastal cities, waterfront development significantly reduces the cooling effect of sea breeze, hence exacerbating the urban heat island effect in inland regions [35].

Even though many studies emphasize the need of optimizing ventilation to mitigate the impacts of the UHI effect, it is necessary to keep in mind that thermal comfort is also significant in a variety of contexts. Higher wind speed is certainly desirable in summer but can cause discomfort in winter [34,36]. A greater wind speed may be required if a pedestrian is partially shaded, while a lower wind speed may be preferred if the air temperature is cooler [37]. Therefore, it is necessary to comprehensively evaluate the wind's effect on the thermal environment according to different climate contexts, activities, and needs [38]. Additionally, thermal comfort is a subjective matter. It is difficult to extrapolate with precision for an individual's subjective thermal comfort from meteorological and climatological measures alone. Due to psychological, sociological, and cultural factors, inhabitants of different locations experience distinct thermal experiences in comparable temperature conditions [26]. As a result, in addition to quantitative measurements, qualitative methods have been employed to assess residents' perceptions of thermal comfort [39].

3.2.2. Energy Conservation

The benefits of wind in terms of energy conservation are evaluated at the building level, as buildings require energy to supply occupants with adequate thermal conditions. According to studies, interior and outdoor ventilation performance have variable effects on the energy efficiency of buildings [40]. As a result, incorporating natural ventilation features in individual building is becoming a more popular design option since it offers a desirable thermal environment while also offering the potential for significant energy savings and emission reduction [41]. In conjunction with other techniques, empirical research demonstrates the effect of natural ventilation that changes indoor temperatures and influences the building's overall energy efficiency [42–44]. However, temperature is not the only element that impacts the energy usage of a building. Noise and pollution can influence the energy-saving potential of natural ventilation. As both air quality and noise levels are significant determinants for whether a building's occupants choose to open windows, both factors can have a significant impact [45].

Studies have found that at the city level, the loss of annual cooling energy due to noise is comparable to that due to air pollution [46]. Further studies have highlighted the importance to expand the scale of building energy evaluation. The building scale energy analysis was unable to predict the impact of tall buildings built in a low-lying urban area, which limited passive ventilation potential and energy efficiency by impeding wind flow [47]. A study in metropolitan regions with a high population density during the summer revealed that outdoor thermal settings had a significant influence on urban energy consumption [48].

Different climate contexts must also be accounted for in terms of the energy conservation features for urban ventilation. Large-scale temporal simulations of building energy consumption reveal that wind speed has the greatest effect on building energy consumption [49]. A study conducted in colder areas revealed that winter household power usage is substantially correlated with the adoption of windbreaks that limit incoming wind speed [50]. The effect of ventilation on energy consumption was found to be greatest in cities with the largest seasonal climatic variations. In these locations, cities with efficient ventilation decrease summer energy use but increase winter energy demand [51].

3.2.3. Health and Wellbeing

One of the biggest threats to the health and wellbeing of urban residents is poor air flow and resulting poor ventilation [52]. In addition to thermal comfort, the most significant function that urban ventilation has on health and wellbeing is the dispersion of air pollution. Indeed, air pollution is a major health problem across the globe, especially in cities in developing countries that are experiencing a rapid pace of urbanization [53].

Addressing air pollution through ventilation necessitates viewing cities as living entities that breathe, delivering clean and fresh air into their tissues, and therefore diluting pollutants trapped in urban canyons. This is a simile to the biology discipline. Consequently, interdisciplinary terminologies, such as breathability, were previously utilized to define the pollutant dispersion capacity of urban areas [54,55]. While wind speed is vital for the dispersion of air pollutants, the wind direction pattern is more important, according to Krüger et al. [56], since wind not only disperses urban air pollution, but may also move pollutants from industrial to residential areas [57].

As such, the term ventilation corridor was widely used [23,58,59]. The premise is that the air outside cities is relatively clean, and that wind may bring this cleaner external air into the urban area while also removing contaminants. As a result of the interaction between the entering atmospheric flow and the building blocks, this capability is directly linked to the patterns of air flow that occur inside the urban canopy [60,61]. Water bodies, green fields, and road networks can function as ventilation corridors which direct airflow through the urban canyons and have shown a substantial effect on improving urban air quality [25].

Depending on the scope and approaches of the study, both thermal comfort and the dispersion of urban pollutants are being studied at various geographical scales. Airflow within urban regions is typically categorized into four geographical scales, i.e., street, precinct, city, and region [54]. Airflow within the urban canyon is explicitly addressed in the preceding three microscales. At theses scales, the quality of urban air relies on the features of the street, precinct, and city [54]. Cities are handled as a larger roughness feature in regional scale studies to provide boundary conditions for smaller-scale analyses, and often incorporated within city-scale assessments for pollution dispersion [57].

3.3. Wind in the Context of Urban Energy

Wind energy has emerged as one of the most rapidly developing renewable energy sources. Nonetheless, most of the developed and committed developments were for huge onshore and offshore projects located far from cities. The premise is that rural wind flow is generally faster, steadier, and more predictable compared to that in urban areas [62]. Nonetheless, there is substantial potential for wind energy exploitation in urban environments, and there are numerous developments worldwide [63–65]. The establishment of an effective wind energy system closer to the point of use may satisfy the local power demand while minimizing the usage of fossil fuel-based energy generation, and therefore substantially reduce greenhouse gas emissions. According to the findings of the literature review, if appropriately utilized and integrated into the current energy grid, wind energy is a viable renewable energy alternative. It has the potential to be incorporated into low-emission building designs, and technology developments have led to an increase in the number of urban wind turbine installations that are more efficient and less expensive. This review acknowledged the complexities of urban aerodynamics and its connection to wind energy outputs. To reconcile this complexity, this portion of the study attempts to highlight the important developments of wind energy research in urban settings, with a focus on their significance to the future urban planning and design process.

3.3.1. Renewable Energy and Grid Integration

One of the major premises of renewable energy development within city boundaries is that most supplied energy is generated by distant, large power plants that are connected to a high-voltage transmission network. Using low-voltage distribution networks, energy will be transferred and subsequently delivered to end-users [66]. This centralized model has yielded economies of scale and reliability, but it has considerable disadvantages. A portion of the energy may be lost during transmission and distribution, and large centralized power plants necessitate substantial capital investments [67]. Thus, the notion of microgeneration or decentralized or distributed energy generation has emerged [63,68].

Distributed generation often involves the installation of small, grid-connected devices that capture renewable energy sources near the customer. As one of the most established and mature renewable resources, much work has been devoted to exploiting wind energy and enhancing its applicability in urban areas. Due to the turbulent and unpredictable wind profile in cities and the overall volatility of urban wind speed, a small variance in expected wind speed can result in a significant difference in possible wind power outputs [69,70]. Consequently, a substantial amount of study has been dedicated to the evaluation of wind patterns, such as seasonal variations in wind speeds and directions, at probable turbine installation sites [68,71,72].

Theoretically, urban wind energy harvesting is optimal in relatively flat and open locations, such as urban peripheries, where there is less surface drag that would cause turbulence [71]. However, low-density locations with relatively smooth surfaces were regarded unsuitable for the construction of large-scale urban wind turbines due to the low average wind speed near the surface [72]. Certain urban locations with the most complex wind conditions, such as dense urban centers, are considered as potential sites for the installation of urban wind turbines [71,73]. It was recommended that urban wind turbines be installed on or around tall structures where wind speeds can reach peak values [74,75].

However, tall buildings in places with a high building density may not always result in significant wind energy potential, as they may obstruct the prevailing wind [76]. The proper assessment and installation of wind turbines in these windy locations thus become the key to increase distributed wind energy output.

Conducted studies have shown that urban wind energy harvesting is more effective when combined with other urban renewable energy sources such as solar or biomass [77]. Urban wind energy alone is not only inefficient in terms of cost, but also insufficient to meet the overall urban energy demand, much alone the requirement for thermal heating [78,79]. The same concept applies to photovoltaic systems, which are a more popular alternative to urban wind turbines [80]. A hybrid renewable energy system that combines solar, wind, and other sources can be more cost-effective than a single form renewable energy generation [81]. Given the huge cost and efficiency benefits, wind energy harvesting is frequently mentioned in studies on distributed generation with a hybrid system [80–82].

According to empirical research, the combination of solar and wind can potentially meet the energy needs of large buildings [83]. In other instances, if the performance of wind energy is inadequate, the outputs might be used to assist the operation of other renewable energy devices [77]. In addition, the hybrid energy system must be carefully assessed and well-managed to minimize conflicting outcomes, such as choosing the correct mix of renewable energy and related infrastructure [77,78].

3.3.2. Emission Reduction

Since urban wind energy harvesting has shown the possibility of integrating into the existing energy grid and contributing to the fulfilment of urban energy demands, new concepts for urban development have evolved, such as "net zero buildings" and "positive energy buildings" [43,44,79]. The net zero buildings focus on producing as much renewable energy as they consume, whereas the positive energy buildings produce more than they consume. Although distinct in definition and scope, they share a common concept and set of strategies: mitigating the environmental effects of greenhouse emissions by integrating renewable energy into the built environment. A number of studies discovered that urban wind turbines save more carbon emissions than other renewable energy sources at a lower cost, if put in places with abundant wind resources [62]. The whole life cycle of a wind turbine, which includes carbon-intensive processes such as manufacturing, transport, and recycling, must be accounted for in emission calculations [63].

As stated in Section 3.2.2, building energy analysis should not be restricted to the building level. Net zero buildings or positive energy buildings are fundamentally focused on energy performance on-site, with most of the attention placed on the building level [43,74]. For a more precise estimate of emission reduction, it is necessary to include both the interdependence of buildings and the urban area in which they reside [47]. Studies have sought to broaden their focus beyond specific structures. Larger city size spatial analysis greatly increases the level of complexity by combining a larger number of influencing variables and interdependencies; therefore, city size special analysis may produce less reliable findings. [68,71]. An intermediate scale, such as a neighborhood, appears to be an appropriate scale for going beyond the boundaries of a single structure without losing its robustness and, at the same time, is capable of addressing tangible solutions to a collection of buildings [69,79,84].

3.3.3. Technology as an Enabler

The expansion of earlier niche urban wind energy development has been made possible by technological advancements, particularly in turbine technology. The two foci of urban wind turbine research are on the design and positioning of turbines. Horizontal-axis wind turbine (HAWT) and vertical-axis wind turbine (VAWT) are the two common types of wind turbine designs [85]. Due to the technical maturity of HAWTs, the majority of large-scale wind farm and early urban wind turbine designs are primarily based on them, leading to lower costs and greater generation capacity [65]. However, HAWTs are highly sensitive to wind direction and do not function effectively in turbulent airflow [65]. As a result, urban HAWT installations have experienced underperformance relative to manufacturer data [66,86,87].

In the often slow and unsteady urban wind environment, the performance of these HAWT turbines degrades significantly. As manufacturers publish power generation curves, only ideal sites and uniform wind conditions have been considered [86]. Thus, research suggests that performance criteria for wind turbines should not only be based just on wind speed, but also on turbulence or gust intensity, which is the sudden rise in wind speed. If forecasts are accurate and turbine adjustments are made appropriately utilizing sophisticated monitoring systems, energy outputs may be improved [88].

VAWT is a relatively recent idea in turbine design, and its use is restricted to satisfy modest energy demands [67]. Two kinds of VAWT exist: Darrieus and Savonius. The Darrieus VAWT is the most researched type and is viewed as a viable alternative to HAWTs for urban applications due to its comparable generation capacity, whilst the Savonius VAWT has a lower generation capacity but is less expensive and easier to construct [67]. Both types of VAWT are deemed suitable for urban applications due to their ability to function effectively in turbulent wind conditions. In addition, VAWT is quieter, produces less vibration, and is relatively more aesthetically pleasant than HAWT [65,67]. However, VAWT designs are still considered immature and suffer from a lack of comprehensive and dependable long-term performance data, resulting in poor market acceptability. If costs, performance, and reliability reach a particular level, novel turbine designs and dependable testing results may result in greater urban VAWT deployment [67].

Urban wind turbine installation location falls into three categories: standalone, rooftop installation, or architecturally integrated into buildings [85]. The architecturally integrated approach is referred as a building integrated wind turbine (BIWT) [85]. A stand-alone wind turbine away from buildings has a few advantages, including the fact that the turbine is located away from buildings and their occupants, minimizing the influence of the turbine's noise and vibration [85].

Alternatively, rooftop or architecturally integrated wind turbines can harvest more energy by taking advantage of stronger wind speeds at a greater height [65,89]. Consequently, most large-scale urban wind turbines are BIWTs. Due to the restricted number of available building spaces, BIWTs may only meet a small fraction of the energy demand. Innovative designs that combine turbines with cooling towers, water harvesters, and solar panels may help circumvent this issue [83].

As turbine technology continues to progress, studies have highlighted the need of adopting updated wind assessment guidelines based on empirical data [67,85]. Real-world operation of urban wind turbines has shown multiple instances of zero outputs and inconsistencies, suggesting that actual performance may differ from modeling and testing results, as was proven in field studies [86]. Therefore, it becomes crucial that urban wind turbine performance is validated by not only turbine designs and positioning, but also by factoring the impacts of urban aerodynamics [85]. As a result, the methods of measuring urban aerodynamics in connection to ventilation and energy are constantly undergoing development, and state-of-the-art methodologies, such as machine learning and artificial intelligence, have been included in the process [90,91]. In addition, the proliferation of sensors and real-time monitoring technology may reduce the level of uncertainty associated with wind forecasting in urban areas, which formerly relied on weather stations situated far from the installation site [77].

3.4. Wind in the Context of Urban Planning and Design

A great portion of academic discussion on the implication of urban wind environment has focused on the topic of wind hazards and many countries have codes and design guidelines for urban planning and design in relation to gust and strong wind problems [37]. Based on the above discussion, good wind urban environment can greatly benefit the sustainable development of a city. As such, there has been growing attention to the question of "how urban areas and its wind environment can be optimized that leads to better ventilation and energy production?" [28,92]. Because urban geometries and configurations have a substantial impact on the urban wind environment, urban aerodynamics and wind engineering become the quintessential research subject that must be understood in depth. Considerable progresses have been documented in the past years to comprehend the aerodynamics of urban environments, and the urban wind flows continue to be extensively investigated with a variety of novel methodologies and techniques [90,93].

The challenge that arises next is the incorporation of urban wind engineering knowledge into urban planning and design practices. A substantial number of studies have been devoted to bridging this gap by identifying morphological parameters that affect the urban aerodynamics response and provide relevant design guidelines [22,92]. The morphological studies, albeit essential, are subject-specific, focusing on either ventilation or energy production. To reconcile this issue, this section presents a brief overview of the pertinent parameters and indices derived from empirical research. Then, the common themes between ventilation and energy production are provided. The primary objective of this section is to give a qualitative review that synthesizes findings from selected wind ventilation or energy production studies and highlights relevant suggestions that may be translated into improved urban planning and design practices to maximize wind's benefits in cities.

3.4.1. Urban Morphology

The term urban morphology, as used here, refers to a three-dimensional urban spatial structure created by a collection of buildings and open areas, beyond building features. Relevant morphological parameters and indices that impact the wind environment may be determined from the urban spatial structure analysis. Studies have included a range of quantifiable urban morphological parameters and indices that influences urban aerodynamics, for example, surface roughness [71,94,95], sky view factors [56,96,97], frontal area density and index [14,32,51], plan area density [13,22,75], building coverage ratio [98], building height and height variance [25], and height-to-width ratio [99]. These morphological parameters are analyzed alongside quantifiable ventilation and energy performance indicators such as temperature changes [14,24,100], age of air [99], air exchange velocity [101], pollutant concentration [59,60,102], energy density [73,103], and turbine capacity factor [71]. Noting that multiple indices are reported in feature articles, individual indices should not be considered as exhaustive representations of either ventilation or energy production.

Urban density is a fundamental concept that frequently appears in featured articles. The term is highly ambiguous, context-dependent, and utilized differently across study areas. Density can be based on individual parameters or their combination relating to street layouts, building types, space arrangements, and landscape element [104–106]. Density is also scale-dependent, and the quantifiable results can be blurred by enlarging study resolution, as mentioned in Section 3.2.3. Despite its ambiguity, a common theme can be found, which is the discourse on the notion of "high-density" or "compact" development impacts on urban wind environment [30,107,108].

High density or compact development is a blanket term used to describe areas with higher building volume and height, lower distance between buildings, and narrower streets [51,107]. It is often viewed as advantageous during urban sustainability initiatives due to its potential to enable higher usage of public transportation and the preservation of land resources [30]. Conversely, high density or compact development can lead to a decrease in urban wind speed, while also suffering from UHI intensity and severe air pollution [61,109]. High density or compact developments also present a unique opportunity for energy production. As noted by several studies, wind energy production is better suited at higher altitude above the surface [65,73]. Vertical, high-rise developments characterized by high floor density could host a few wind turbines either on the roof or between buildings to harness the above-average wind speed and utilize the larger space in these locations [70,76,92]. However, high density environments can also lead to turbulence and unwanted gusts that hamper energy production [73].

Given ventilation and energy production potential is highly dependent on wind condition, high density urban development could consider increasing its wind penetration within its urban canyon. There are several specific areas of improvements.

First, the development of breezeway and wind corridors by the use of coarse and dense alleyways, roadways, and interconnecting open areas might ensure deep penetration of prevailing winds into cities [36,42,105]. Second, lowering building coverage and plot area density to provide proper spacing between buildings increases urban porosity and decreases wind blocking at the pedestrian level [39,94,99]. Thirdly, rather than a constant building height in the prevailing wind direction, a specific building height variation is required so as not to impede wind flow [54,91]. Fourthly, urban tree planting must be monitored carefully to avoid obstructing wind flow in locations such as waterfront and downwind areas [110,111]. Large building frontal surface areas should be oriented away from the prevailing wind direction to minimize wind obstruction and building arrays should be oriented towards the prevailing wind to allow cross-ventilation [32,51,102,112].

Nonetheless, it is possible that qualitative description may not systematically capture the effect of wind on overall ventilation or energy performance. For instance, street orientation may not be as important as building configuration in high-rise precincts [28,40,58]. Research indicates that the influence of wind on thermal environment in high density areas may not be as significant as that of shade, since solar radiation impacts the thermal environments more [29]. Even though wind exerts less effect than solar radiation, another study found that the wind's capacity to cool was greater in larger open regions. However, if the background temperature is higher, the influence on cooling is greater than that of solar radiation [106]. This again emphasizes the need for design guidelines to properly reference the site environment.

3.4.2. Building Typology

The prior section focuses on spatial elements such as lot, streets and building configuration. This section focuses on the fundamental building design features covered in the selected articles. Building parameters that impact the urban wind environment include building height [25,89,92], building permeability [94,98,113], façade features [101], corner characteristics [75,92], and roof shapes and types [75,99,114].

Other building level features may include plot size and building plot coverage attributes, which were addressed in the preceding section. Plot size is frequently determined by a building's setback. Consequently, lot sizes can have a substantial effect on the width of an urban canyon, which impacts wind conditions [37]. Studies conclude that the impact of building typology such as building height on urban wind conditions is not as substantial as that of morphological factors such as building density [22]. The rationale is that the localized building wind environment is a by-product of the urban wind environment [107].

Urban morphology relates to the general aerodynamics of cities, which has implications for both ventilation and energy production. Building typologies are more topic-specific and narrowly focused. Building permeability and façade features are frequently used in the analysis of the natural ventilation potential of a building [94]. Building permeability is a quantifiable measurement of airflow through a structure's envelope, including windows, doors, and void spaces [99,113]. Building openings contribute to the pressure differential across building facades, allowing air to be channeled through the structure [37]. Thus, studies have often advocated for greater permeability to promote better-ventilated buildings [43].

However, this can result in conflicts between designs based on appearances and designs based on empirical evidence. Street roofs and building arcades, for instance, can potentially impede wind flow if not designed appropriately; therefore, it is recommended that roofs and arcades be semi-open to allow for more permeability [55,99]. Common façade elements, such as balconies, can also affect the ventilation potential; in particular, windward balconies can change the wind patterns in street canyons. Windward balconies hinder airflow from entering deeply into the canyon, hence limiting wind speed at street level, and increasing the concentration of pollutants [101].

In contrast, investigations have indicated that roof shapes and corner shapes are prevalent factors in wind energy production studies. Wind energy production is extremely sensitive to wind speed and turbulence, as previously stated. Turbulence formation is localized and substantially influenced by the roof and corner geometry of buildings, which significantly modifies the pattern of incoming airflow [75,92]. Round and smooth corners may lead to more energy generation and have lower turbulence intensities over downstream structures than sharp corners [75,92].

In terms of roof design, research has found that dome or vaulted-shaped roofs with a curved geometry are optimal for turbine installation due to their reduced turbulence [75,89,114]. Additionally, wind turbines may be installed on building facades. In contrast to roof wind turbines, research indicates that extending the radius of a building's duct opening has a negligible effect on wind speed, whereas a sharp edge enhances wind speed. Combining a greater radius with a sharp ducted edge increases the potential energy production [103].

3.4.3. Governance as an Enabler

Urban governance is crucial for transforming the scientific findings of the urban wind research into tangible, functional, and practical outcomes. As early as the 1980s, European towns such as Stuttgart and Graz considered the influence of wind on thermal and air quality in the context of urban ventilation [36]. To improve ventilation, land use and building performance targets were established to maximize wind access. The city administrations of high-density East Asian cities, such as Tokyo and Hong Kong, embraced European cities' relevant expertise and knowledge, and developed their own planning and design practices [37]. Emerging cities in China have implemented a series of wind related planning and design directives to combat the significant degradation of their urban wind environment due to rapid urbanization [23].

Indeed, considerable macro-level contributions from governments are a crucial component of a functional urban ventilation system [39]. Although the consideration of urban ventilation is widely accepted, the corresponding practices continue to be extremely context-dependent. In regions where the climate is hot and arid, for instance, large-scale use of vegetation or water bodies may be prohibitively expensive. In circumstances where altering the geometry of outdoor space has been shown to be the most effective passive cooling strategy, the degree to which outdoor space geometry may be adjusted in real projects is frequently constrained [115]. A better wind environment for ventilation can be achieved by lowering building heights and decreasing site coverage by increasing setbacks; however, these measures are often at odds with the pursuit of economic goals [116].

Feature articles on governance in the context of urban wind energy generation tend to focus mostly on the socioeconomic impact of wind turbines. The two most important considerations in wind turbine governance are economic viability and public acceptance. Wind turbines, as discussed in Sections 3.3.1 and 3.3.3, may be unviable and inefficient due to their high financial cost and poor energy-generating capacity in some circumstances, as well as because they generate nuisances such as noise and vibrance. Regarding wind turbine design and energy system optimization, appropriate urban policies must be in place before they can be enabled. A financial incentive known as a "feed-in tariff" is commonly offered by governments or utilities to encourage more renewable energy generation, in this case, utilizing wind power [64,68,117].

Early adoption of this strategy in the UK appears to have increased the incentive for user installation, but it was regarded a gross economic loss, primarily due to low energy capacity and higher operation costs [64]. Consequently, research suggests that providing a discount on energy bills is more effective than offsetting the initial capital committed by households to counter their high operational expenses [117,118]. In terms of social acceptability, it appears that the public's attitude towards the installation of urban wind turbines deviates from the previous assumption of "not in my backyard (NIMBY)" due to nuisance, and includes other layers of concerns, such as the distrust of technology, businesses, and public institutions [119]. Local public opposition and distrust towards wind turbines may result in significant project deficiencies, such as a reduction in the scope of adoption [120].

By comparison, creating greater public acceptance not only increases local community members' receptivity to the presence of wind turbines, but also increases self-investment intentions and "wind-energy enthusiasts" [121]. Various urban planning methods have been recommended to boost their responsiveness to wind turbines. The small wind turbine development in Dundee, Scotland, was used to illustrate how planning systems may serve as a mediator between the state, the energy market, and the community. The findings indicate that well-considered strategy planning must incorporate the perspectives of all relevant stakeholders. According to the logic, the objective of planning was to promote democratic conversation over the most effective means of serving the public interest [122].

Exploratory research was conducted to examine how different planning systems responded to the introduction of new technologies. The results indicate that there is no best practice, and that convergence of practices is unlikely until further implementations are created. There are two ways to enhance land control for tiny wind turbines: strategically and experimentally. Initiatives involving wind turbines require a comprehensive set of adaptable policy guidelines as part of their overall strategy. In an experimental strategy, ad hoc approaches may serve to strike a balance between the mobility of technical niches and the rigidity of land use regulations [123].

Ventilation and wind energy production both require the optimization of the existing urban fabric to enable a better wind environment in cities. This requires expert knowledge from a wide range of disciplines, including urban physics, climatology, mechanical and wind engineering of wind turbines, and planning and design practices. Government, developers, and academics from a variety of fields need to collaborate and synthesize their knowledge into effective solutions based on clear communication on an easily understandable platform [23,84].

4. Findings and Discussion

4.1. Conceptual Framework of Wind Sensitive Urban Design

Existing studies concentrate on maximizing the advantages of urban wind in two main areas. These are ventilation and energy generation. Improved thermal comfort, reduced energy consumption, and enhanced health and wellbeing have all been related to adequate ventilation in urban areas. Urban wind energy generation, on the other hand, is a niche area that has the potential to greatly reduce urban carbon emissions, if properly integrated with other renewable energy sources. However, significant technological deficiencies still exist for urban wind energy generation in terms of turbine design, meteorological forecasting, and urban aerodynamics. Ventilation and wind energy generation efficiency are coupled with urban forms, which significantly modify the urban wind environment. As such, urban climatologists and building scientists have used state-of-the-art models and simulation to analyze the influence of urban form parameters on either ventilation or energy generation performance. A number of cities worldwide have included wind accessibility into urban planning and design standards. On the other hand, research has identified obstacles to the inclusion of urban wind energy in cities, in addition to emphasizing the importance of transdisciplinary collaborations.

In recent years, a related new term was coined by several scholars, namely, wind sensitive urban design (WiSUD) [14,15,124]. According to the literature, because urban tissue has a strong link with wind condition and affects thermal environment and air quality, urban planning and design as an intervention tool must consider the influence of wind on these aspects. Nonetheless, the studies neither explored the influence of wind from the viewpoint of wind energy generation, nor comprehensively elaborated the term or offered a conceptual framework.

Building on the findings of the systematic literature review, a conceptual framework for WiSUD was developed with the identified key domains and sub-categories (Figure 5). The framework is organized in the four domains: (a) passive wind measures; (b) active wind measures; (c) governance; (d) planning and design.

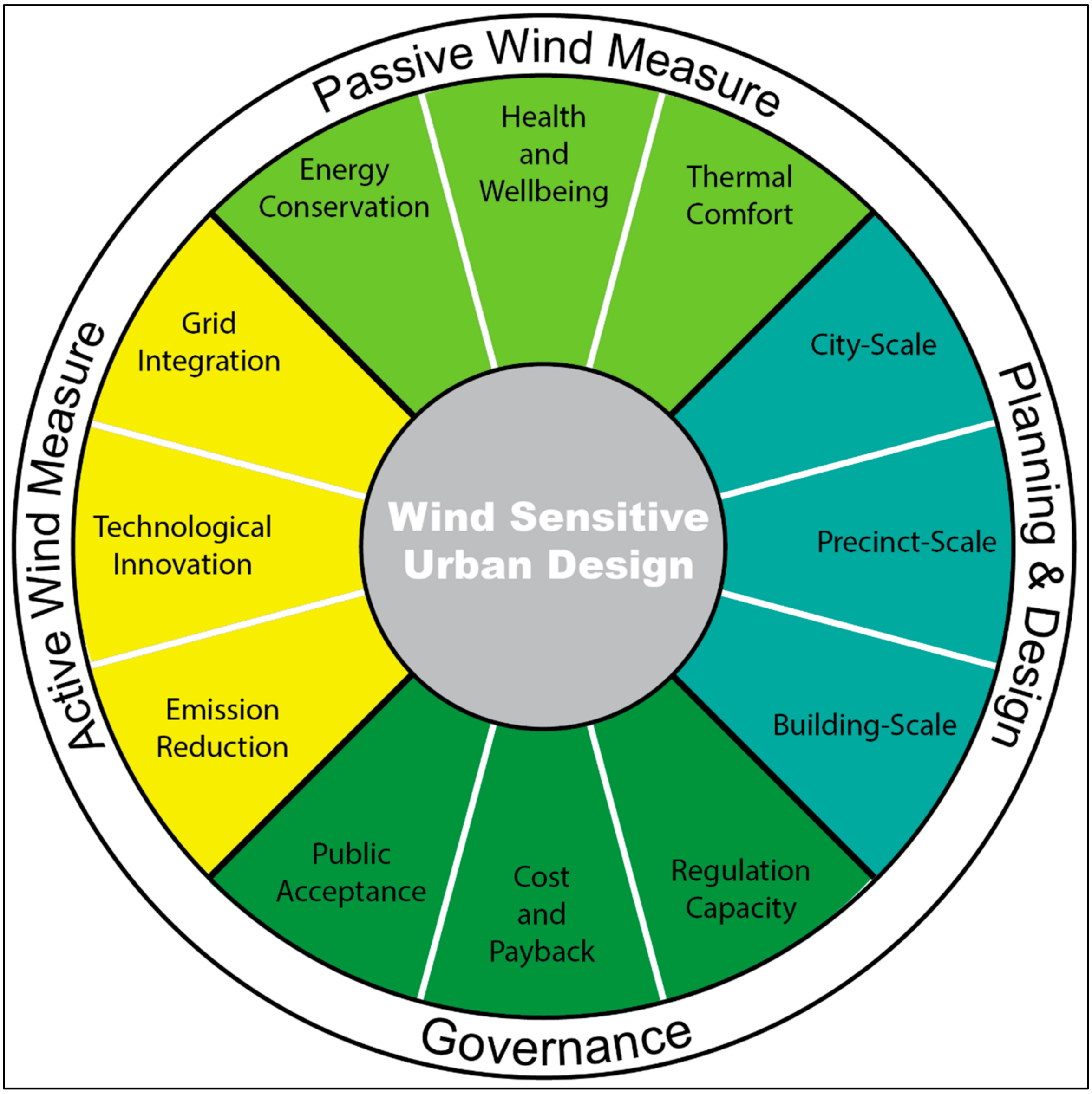

Figure 5. Conceptual framework of wind sensitive urban design.

The passive wind measures domain includes indicators for measuring ventilation quality, which contains the sub-categories of: (a) energy conservation; (b) thermal comfort; and (c) health and wellbeing. This domain aims to measure the quality of WiSUD and its actual impact. Urban ventilation and energy generation can be improved by WiSUD. Energy conservation is to be achieved using urban wind as an active component to flush out unwanted heat and pollutants. Another outcome of the process is that the overall health status of occupants can be measured to quantify the positive impact of WiSUD on the community. Furthermore, a positive wind environment potentially enables wind energy harvesting infrastructure in the built environment.

The active wind measures domain highlights the urban wind generation component of WiSUD, articulated in the sub-categories of: (a) grid integration; (b) technological innovation; and (c) emission reduction. This domain deals with turbine selection and placement, and integration with the existing grid and other renewable resources. The technology innovation demonstrates the needs to improve computational methods and sensors for accurate wind resource prediction, as well as innovative turbine designs.

The governance domain has three sub-categories as strategic enablers for urban wind. The reviewed literature in this area highlights the need for: (a) regulation capacity, in the form of planning frameworks and design guidelines, where regulatory capacity regards the necessary legislative framework and guidance to foster a positive understanding and uptake of the advantages of WiSUD; (b) cost and payback, which summarize the economic aspects of WiSUD, which in turn need to consider direct and indirect costs of application of either passive or active wind measures, as well as benefits; and (c) public acceptance, which entails public education and knowledge sharing, for example, data visualization and platform design, and community engagement to disseminate WiSUD at a granular scale.

The planning and design domain deals with the physicality of WiSUD in three sub-categories that can also be considered as scales: (a) city-scale; (b) precinct-scale; and (c) building-scale. The city scale summarizes the principles of the urban tissues that can capitalize on urban wind, and it encompasses variables such as urban density, green spaces, and waterways. The precinct scale includes variables such as street layout, vegetation planting and building arrangements. The building scale supports the optimal design of plot size, building heights, and building envelopes that allows greater wind permeability.

4.2. Research Directions

Concerns about the detrimental consequences of urbanization and climate change have grown since the 1990s. Industrialized countries have subsequently developed a variety of urban development initiatives to remodel and restructure their cities to achieve environmental protection and energy conservation [125]. From the earliest eco-city in the 1990s to smart cities in the 2000s, there have been evolutionary efforts to make cities more ecologically friendly, socially equitable, and economically competitive [126,127]. More recently, the urgency of the climate crisis has led many global cities to pledge to become "net zero" or, even better, "climate positive" within a certain timeframe. Although different guidelines, strategies, and protocols have been developed to achieve this objective, one notion is common, i.e., a rapid and major transition towards decarbonization requires cities to maximize renewable resources usage [128].

The incorporation of wind power into the model of urban development presents a major opportunity. As noted, wind may contribute to the fulfilment of needs for thermal comfort, both indoors and outdoors, as well as for air quality. Integration of wind turbines into the urban environment enables users to harvest energy from nearby wind assets and reduces their vulnerability to external energy price volatility and supply restrictions. Hence, the WiSUD concept framework developed by this study highlights that wind resources within urban areas are an environmental and economic asset that should be leveraged. To sufficiently actuate the WiSUD concept, further research works are required to fill the following key knowledge and research gaps:

- Integration of wind energy with other sources of renewable energy has advanced over the years [129,130]. While urban wind energy is a niche market due to high costs and low payback in urban settings, urban wind energy generation is still worth investigating owing to its potential in a hybrid energy system that would achieve urban carbon neutrality or positivity.
- Exploring the synergy and interplay between ventilation and wind energy research beyond the building scale: There is clearly a lack of synergy between ventilation and wind energy harvesting studies, particular beyond the building scale. Multiple studies have addressed the design of a net zero building or a climate positive building that uses ventilation and wind energy generation strategies to achieve high energy efficiency

or energy independence, and high livability [43,74,130]. Still, these simulations tend to neglect the effects of the surrounding urban form on the wind environment of the building structure. The effect of urban morphology on the performance of renewable energy is frequently ignored, and this shortcoming has been emphasized by numerous studies [131,132].

- Developing comprehensive urban wind resource assessment approaches beyond the building scale: Addressing the design issue beyond the building scale comes at a cost. The most common wind assessment tools identified in the review, such as laboratory wind tunnel experiments and computational fluid dynamics (CFD) analysis can provide very accurate information regarding the wind flow around a building. However, these methods become much more time-consuming and inaccurate for large datasets [124]. To overcome this deficiency, studies have used a mix of simplistic GIS modeling and more sophisticated CFD modeling [110]. The state-of-the-art techniques such as advance sensing, artificial intelligence, machining learning, and deep learning models may facilitate the process utilizing fewer predictor variables. The transferability and applicability of these models, however, require further testing [93].
- In-depth understanding of local context: The literature reveals the integration of climate knowledge into urban decision making is a complex process that requires consideration of historical interaction with scientists, long-term socio-cultural settings of the city, and prior political and policy actions at all levels of government [133]. On the other hand, there are several additional aspects to consider, such as the local climatic condition, the long-term economic and demographic outlook, and technological advancement. To facilitate the planning phase of WiSUD design, the associated factors must be investigated and recorded. Therefore, additional development of WiSUD models for subcategories based on the local context is critical.
- Developing WiSUD guidelines to inform policy and practice: To make our cities carbon neutral or climate positive, the research's lead on also developing straightforward WiSUD guidelines is important. Prospective research is needed to translate urban/wind modeling results into locally tailored policy directions and guiding principles. In this way, urban authorities will be able to develop the needed policy and regulations, and the urban development or construction industry will be able to implement the WiSUD guidelines. Along with this, in-depth studies of the motivations and barriers to adopting WiSUD at an institutional level are highly desired.
- Exploring pathways for knowledge exchange and collaboration: Communication of results is a key factor for success, and it is also important that relevant climate analysis meets planning's demand-driven needs by providing suitable methods and tools. It is imperative to develop a simplistic, open, and transparent platform, so that the government, developers, and academics from a range of sectors can work together to synthesize their expertise into practical solutions [23,84]. In addition, scholars have identified the need to improve the earlier institutional deficiencies of transferring urban climate knowledge into sensible planning and designing processes and practices [134].

Lastly, we advocate that WiSUD should be understood in the context of other nature-based urban design approaches, notably water sensitive urban design (WSUD) and biophilic sensitive urban design (BUSD) (Figure 6). Water, wind, and flora have been the fundamental elements of nature-based design since time immemorial. However, with industrialization, technology-based systems have dominated design thinking and these fundamental elements have until recent decades been relegated to the periphery of design thinking in industrialized urban countries. More recently, WSUD and BSUD thinking has come to the fore, while WiSUD is still to be fully understood by the urban design industry as a key nature-based design approach. The benefits of nature-based urban design approaches are that they can be effective from an operational cost and environmental perspective in lessening the energy and pollution loads on complex mechanical, electrical, and material engineered systems, as well as providing an incalculable human-nature-oriented design benefit.

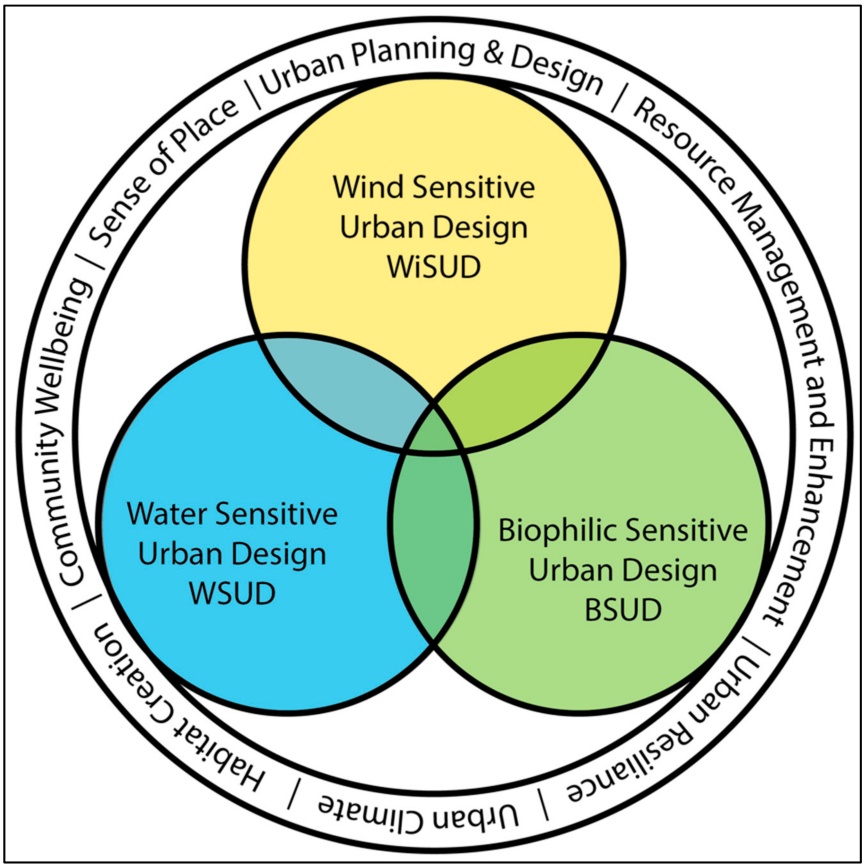

Figure 6. The nature-based urban design approaches.

4.3. Study Limitations

This paper placed literature on wind and the city under the microscope of a systematic review and conceptual analysis to address the issue of leveraging the opportunities of wind for cities through urban planning and design. The findings generated insights and formed a conceptual framework of WiSUD. Although the research team minimized the limitations of the study as much as possible, the following possible restrictions should be noted when interpreting the results: (a) identified search keywords and target databases may not cover all articles relevant to the research objective; (b) only peer-reviewed journal articles that were available in full-text were included in the analysis; that is, information from book chapters, conference proceedings, and white papers are omitted; (c) similarly, grey literature such as government policy documents, and industry reports and websites, were not considered; (d) the results might have been influenced by unintentional biases of the authors; and (e) the methodological approach is limited to a manually handled review technique; further analytical techniques could be considered, such as bibliometric, scientometrics, content analysis, cognitive mapping, and concept clustering techniques. These limitations will be addressed in our prospective studies.

5. Conclusions

Even though it is one of the oldest known forms of renewable energy that may be harnessed for ventilating cities and generating energy, urban wind has not yet been substantially integrated into the planning and design of sustainable and resilient cities. The current study evidenced the importance of future research for leveraging the opportunities of wind for cities through urban planning and design. Moreover, this study expands the term WiSUD by developing a novel conceptual framework that aims to establish wind as a useful renewable asset and provide pathways to integrate wind into the urban planning and design process. In turn, this will help our cities become carbon positive.

The overall findings of the study revealed that: (a) improving the urban wind environment via sound urban planning and design may enhance urban ventilation and energy performance; (b) better urban ventilation and energy performance enable cities to become climate positive or net zero and relieve the urgent climate crisis; and (c) WiSUD is an emerging research area that is critical to harvest the benefits of wind for cities.

The specific findings of the systematic literature review unveiled that: (a) optimizing the urban wind environment may improve the thermal environment and air quality, resulting in reduced energy use and improved health outcomes; (b) leveraging urban wind to generate energy at a given site alongside other renewable energy sources may significantly reduce urban carbon footprints; (c) turbine and wind assessment technology needs to be further improved for efficient urban wind energy generation; (d) WiSUD requires comprehensive understanding of the local urban context, including urban form, governance, and socioeconomic conditions; and (e) currently, urban ventilation, urban wind energy generation, and urban planning and design studies are disconnected.

This study contributes to worldwide research efforts to combat the climate crisis by incorporating renewable energy into the urban planning and design process by proposing the WiSUD conceptual framework. From an academic standpoint, this study underscores the need for increased attention to be devoted to the study of urban wind environment and its implications for urban sustainability and resilience. From a professional practice perspective, the WiSUD framework has value during urban development planning and implementation for the assessment of the impact of urban wind, and prospective ventilation and energy performance enhancements. We also underline the critical need for future research to inform urban policy formation and diffusion for better urban and environmental performance [135]. Our prospective research will focus on advancing the conceptual framework into an operational assessment framework and undertaking empirical WiSUD modeling studies.

Author Contributions: Y.S.L.: Data collection, processing, investigation, analysis, and writing–original draft; T.Y., M.G., K.D. and A.L.: Supervision, conceptualization, writing—review and editing; M.K.: writing—review and editing. All authors have read and agreed to the published version of the manuscript.

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Appendix A

Table A1. Reviewed literature (★ = Full focus, ☆ = Partial focus, ☐ = No focus).

			Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design							
Primary Focus	**Authors**	**Title**	**Thermal Comfort**	**Energy Conservation**	**Health and Wellbeing**	**Renewable Energy and Grid Integration**	**Emission Reduction**	**Technology as an Enabler**	**Urban Morphology**	**Building Typology**	**Governance as Enabler**	**Methodolog**	**Geographic Scale**	**Study Region**	**Aim**	**Relevant Findings**
Urban Ventilation	Capeluto et al. [33]	Climatic aspects in urban design —A case study	☆	☐	☐	☐	☐	☐	★	☐	☐	CFD Modeling	Precinct	Middle East	Case study for business district design which takes climate aspects into consideration	"Descriptive approach not ideal. To maximize wind penetration, performance standards should be established, and the wind pattern around the building should be evaluated against these standards."
	Liao et al. [113]	Size-dependent particulate matter indoor/outdoor relationships for a wind- induced naturally ventilated airspace	☐	☐	★	☐	☐	☐	☐	★	☐	Statistical Analysis	Building	East Asia	Characterize indoor and outdoor relationship for wind-induced naturally ventilated residences	"Wind-induced natural ventilated space depends strongly on the ambient particle distributions, building openings design (e.g., height-to-length ratio of openings and roof slope)."

Table A1. *Cont.*

Primary Focus	Authors	Title	Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design			Methodolog	Geographic Scale	Study Region	Aim	Relevant Findings
			Thermal Comfort	Energy Conservation	Health and Wellbeing	Renewable Energy and Grid Integration	Emission Reduction	Technology as an Enabler	Urban Morphology	Building Typology	Governance as Enabler					
	Stathopoulos et al. [26]	Outdoor human comfort in an urban climate	★	□	□	□	□	□	★	□	□	Statistical Analysis Field Study	City	North America	Investigating the comprehensive relationship between the comfort level of typical human activities and major weather parameter	"Reveals the integrated effects of wind speed, air temperature, relative humidity and solar radiation on the human perception, preference and overall comfort in an urban environment."
	Capeluto et al. [38]	A methodology for the qualitative analysis of winds: Natural ventilation as a strategy for improving the thermal comfort in open spaces	★	□	□	□	□	□	□	☆	□	Climate Modeling	Building	Middle East	Present a simple computer-aided design strategy for enhancing thermal comfort in the built environment by managing wind access and prevailing wind obstruction	"Site geometry was designed to improve three aspects of thermal comfort: comfort, thermal and wind, depending on activities and needs."
	Masuda et al. [35]	A Basic Study on Utilization of the Cooling Effect of Sea Breeze in Waterfront Areas along Tokyo Bay	☆	□	□	□	□	□	★	□	□	Wind Tunnel Modeling	Precinct	East Asa	Surveyed the temperature and wind condition difference between a inland and adjacent coastal district to understand the cooling effects of sea breeze	"Coastal district reduces the overall cooling effects of sea breeze and resulted in higher temperature in inland district."

Table A1. *Cont.*

			Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design							
Primary Focus	**Authors**	**Title**	**Thermal Comfort**	**Energy Conservation**	**Health and Wellbeing**	**Renewable Energy and Grid Integration**	**Emission Reduction**	**Technology as an Enabler**	**Urban Morphology**	**Building Typology**	**Governance as Enabler**	**Methodolog**	**Geographic Scale**	**Study Region**	**Aim**	**Relevant Findings**
	Ghiaus et al. [45]	Urban environment influence on natural ventilation potential	★	☐	★	☐	☐	☐	✩	☐	☐	Statistical Analysis	Street	Europe	Quantify the different impact on urban ventilation performance	"Urban form, noise and pollution could reduce wind speed and ventilation performance."
	Ng [37]	Policies and technical guidelines for urban planning of high-density cities-air ventilation assessment (AVA) of Hong Kong	✩	☐	✩	☐	☐	☐	✩	✩	★	Qualitative Analysis	City	East Asia	The primary objective of this study was to explore the feasibility of establishing procedures to assess the effects of urban development proposals on acceptable wind environment	"A guideline for wind ventilation was provided where wind velocity ration is the main indicator. Discussion of various urban and building morphology and typology parameters were provided: breezeway/air path, orientation of street grids, linkage of open spaces, waterfront sites, building height, podium and disposition."
	Kruger et al. [56]	Impact of urban geometry on outdoor thermal comfort and air quality from field measurements in Curitiba, Brazil	★	☐	★	☐	☐	☐	★	☐	☐	Climate Modeling	City	South America	Observed and estimated relations between urban morphology and changes in microclimate and air quality within a city center	"Sky view factor and temperature has a lower correlation with the influence of wind speed. With relatively low wind speed (1.2 m/s), pollutants concentration could be removed."

Table A1. *Cont.*

Primary Focus	Authors	Title	Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design			Methodolog	Geographic Scale	Study Region	Aim	Relevant Findings
			Thermal Comfort	Energy Conservation	Health and Wellbeing	Renewable Energy and Grid Integration	Emission Reduction	Technology as an Enabler	Urban Morphology	Building Typology	Governance as Enabler					
	Lopes et al. [6]	Urban boundary layer wind speed reduction in summer due to urban growth and environmental consequences in Lisbon	☐	☐	✰	☐	☐	☐	★	☐	☐	Climate Modeling	City	Europe	Assess the change in wind condition, 25 m above buildings due to urban developments in Lisbon	"30% reduction of wind speed was observed in summer and further wind speed reduction in the future due to blockage of prevailing wind by buildings. Recommended wind corridor planning."
	Ng et al. [94]	Improving the wind environment in high-density cities by understanding urban morphology and surface roughness: A study in Hong Kong	✰	☐	☐	☐	☐	☐	★	☐	☐	Spatial Analysis, Wind Tunnel CDF Modeling	City	East Asia	Develop a simple methodology to understand appropriate levels for better ventilation. Results are validated by wind tunnel and CFD modeling.	"Urban morphology at the podium/street level, between 0–15 m has strong impact on air ventilation movement. Ground coverage ratio is a methodology parameter that can be further use in large scale ventilation assessment."

Table A1. *Cont.*

Primary Focus	Authors	Title	Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design			Methodolog	Geographic Scale	Study Region	Aim	Relevant Findings
			Thermal Comfort	Energy Conservation	Health and Wellbeing	Renewable Energy and Grid Integration	Emission Reduction	Technology as an Enabler	Urban Morphology	Building Typology	Governance as Enabler					
	Yuan and Ng [100]	Building porosity for better urban ventilation in high-density cities—A computational parametric study	✰	□	□	□	□	□	★	✰	□	CFD Modeling	Street	East Asia	The approaches rely on parametric research that evaluates the ventilation performance of various design alternatives. The study calibrates simulation outcomes utilizing CFD modeling	"Main streets should be arranged along the prevailing wind direction. Building height matters but on the pedestrian scale, building porosity more important. Decreasing the site coverage ratio helps increase the pedestrian-level natural ventilation. Wind passages should be arranged as close as possible to the ground level. Wind path planning might be more important than building design. Ventilation optimization is possible even in extreme high-density areas."
	Hang et al. [99]	Natural ventilation assessment in typical open and semi-open urban environments under various wind directions	✰	□	✰	□	□	□	★	□	✰	CFD Modeling	Street	East Asia	Quantitatively understand street-roof effect on natural ventilation using five different set of street roof configuration	"Depending on the coverage, street roof lowers the ventilation performance, as measure by the age of air significantly. Semi open street roof is recommended."

Table A1. *Cont.*

Primary Focus	Authors	Title	Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design			Methodolog	Geographic Scale	Study Region	Aim	Relevant Findings
			Thermal Comfort	Energy Conservation	Health and Wellbeing	Renewable Energy and Grid Integration	Emission Reduction	Technology as an Enabler	Urban Morphology	Building Typology	Governance as Enabler					
	Wilson et al. [50]	Urban form and residential electricity consumption: Evidence from Illinois, USA	☐	★	☐	☐	☐	☐	✰	☐	☐	Statistical Analysis	Building	North America	Examines the link between household electricity consumption in Illinois and various urban factors using a linear regression	"Windbreaks which reduce wind-induced thermal loss strongly influences household energy consumption in the winter."
	Yuan and Ng [124]	Practical application of CFD on environmentally sensitive architectural design at high density cities: A case study in Hong Kong	✰	☐	☐	☐	☐	☐	☐	★	☐	CFD Modeling Statistical Analysis	Building	East Asia	Provide a framework for reliably predicting the pedestrian level wind environment and identifying wind-related design concerns	"To promote thermal comfort, this study uses wind speed at the pedestrian level using various test points as benchmarks. The study highlights the usefulness of statistical hypothesis testing to verify and evaluate CFD simulation, comparing with traditional wind tunnelling analysis.""

Table A1. *Cont.*

Primary Focus	Authors	Title	Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design			Methodolog	Geographic Scale	Study Region	Aim	Relevant Findings
			Thermal Comfort	Energy Conservation	Health and Wellbeing	Renewable Energy and Grid Integration	Emission Reduction	Technology as an Enabler	Urban Morphology	Building Typology	Governance as Enabler					
	Hang et al. [54]	City breathability in medium density urban-like geometries evaluated through the pollutant transport rate and the net escape velocity	□	□	★	□	□	□	★	□	□	Wind Tunnel CFD Modeling	Street	East Asia	This paper studies the removal of pollutants at pedestrian level by urban form indices in the urban canopy layer of a medium density location using computational fluid dynamics (CFD) modeling supported by wind tunnelling data	The urban size is the first key factor for pollutant removal. Longer building configuration has less capacity for pollutant removal. Building height variation enhance pollutant removal above the roof.”
	Taleghani et al. [24]	Outdoor thermal comfort within five different urban forms in the Netherlands	★	□	□	□	□	□	★	○	□	Climate Modeling	Street	Europe	To show which of the urban forms can provide a more comfortable microclimate on the hottest day of a year	“Wind velocities are influenced more by urban geometry while courtyard urban form received lesser radiation while having lowest wind speed. Highlighting the higher importance of limiting sky view factor on lowering temperature, comparing to wind speed.”

Table A1. *Cont.*

Primary Focus	Authors	Title	Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design			Methodolog	Geographic Scale	Study Region	Aim	Relevant Findings
			Thermal Comfort	Energy Conservation	Health and Wellbeing	Renewable Energy and Grid Integration	Emission Reduction	Technology as an Enabler	Urban Morphology	Building Typology	Governance as Enabler					
	Da Silva and De Alvarez, [39]	An integrated approach for ventilation's assessment on outdoor thermal comfort	★	□	□	□	□	□	★	✰	★	Statistical Analysis	Precinct	South America	This study aims to determine the effect of ventilation on the thermal comfort of pedestrians in hot and humid coastal environments, using an integrated strategy to analyze urban layouts, thermal perception, and urban legislation	"Urban porosity was shown to be the most impactful urban attribute on pedestrian level ventilation. The feeling of thermal comfort is dependent not only on environmental circumstances but also on the subjective and psychological elements of the individual. The inhabitants of hot and humid areas are indifferent to high temperatures. Local ventilation design not satisfactory. Urban control laws must establish relevant design standard."

Table A1. *Cont.*

Primary Focus	Authors	Title	Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design			Methodolog	Geographic Scale	Study Region	Aim	Relevant Findings
			Thermal Comfort	Energy Conservation	Health and Wellbeing	Renewable Energy and Grid Integration	Emission Reduction	Technology as an Enabler	Urban Morphology	Building Typology	Governance as Enabler					
	Peng et al. [31]	Modeling thermal comfort and optimizing local renewal strategies-a case study of Dazhimen neighborhood in Wuhan city	★	☐	☐	☐	☐	☐	★	☐	☐	CFD Modeling	Precinct	East Asia	Use geometric and mathematical models of wind and thermal comfort to examine the impacts of six small-scale renewal strategies on the wind and thermal environment at pedestrian level in a neighborhood	"Creating efficient wind corridor would create better thermal environment without the needs for large scale demolition of an old neighborhood."
	Hsieh et al. [104]	A simplified assessment of how tree allocation, wind environment, and shading affect human comfort	★	☐	☐	☐	☐	☐	★	☐	☐	Field Study	Precinct	East Asia	Field measurements were carried out in a subtropical park in the summer to investigate the effect of plantings on microclimate and the thermal environment of pedestrian areas	"A rise in temperature was caused by the overcrowding of plants. Thermal comfort can be negatively impacted by trees that are planted without sufficient planning, especially downwind. In urban parks, wind corridors can improve thermal comfort by providing both shade and ventilation, which should be taken into consideration while designing the layout of plants."

Table A1. *Cont.*

Primary Focus	Authors	Title	Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design			Methodolog	Geographic Scale	Study Region	Aim	Relevant Findings
			Thermal Comfort	Energy Conservation	Health and Wellbeing	Renewable Energy and Grid Integration	Emission Reduction	Technology as an Enabler	Urban Morphology	Building Typology	Governance as Enabler					
	Berardi and Wang [29]	The effect of a denser city over the urban microclimate: The case of Toronto	★	☐	☐	☐	☐	☐	☐	✩	☐	Statistical Analysis	Building	North America	Investigate to what extent new urban construction affects surrounding wind environment in Toronto	"On the building scale, new high-rise structures may increase the wind speed near it and reduce the air temperature throughout the day by casting broad shadows."
	Wen et al. [55]	Enhancement of city breathability with half open spaces in ideal urban street canyons	✩	☐	✩	☐	☐	☐	★	★	☐	CFD Modeling	Building	East Asia	The goal of this work is to analyze the flow behavior of the wind permeability around the buildings, with or without an arcade design in an ideal setting	"Tall buildings and narrow streets increase air exchange and ventilation performance. Arcade designs show limited influence but could help with ventilation if designed correctly."
	Lee and Jeong [48]	Impact of urban and building form and microclimate on the energy consumption of buildings: Based on statistical analysis	☐	★	☐	☐	☐	☐	★	★	☐	Statistical Analysis	City	East Asia	Investigates certain correlations between the impacts of urban and building form and microclimate on the energy consumption of buildings	"Higher wind speed shows negative correlation with building energy consumption. Temperature outside of buildings also affects energy consumption."

Table A1. *Cont.*

			Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design							
Primary Focus	**Authors**	**Title**	**Thermal Comfort**	**Energy Conservation**	**Health and Wellbeing**	**Renewable Energy and Grid Integration**	**Emission Reduction**	**Technology as an Enabler**	**Urban Morphology**	**Building Typology**	**Governance as Enabler**	**Methodolog**	**Geographic Scale**	**Study Region**	**Aim**	**Relevant Findings**
	Yuan et al. [111]	A semi-empirical model for the effect of trees on the urban wind environment	☆	□	□	□	□	□	★	□	□	Statistical Modeling	City	East Asia	Built a useful semi-empirical model to give scientific understandings for the landscape design practice by correlating urban density and tree geometry indices with wind speed. Used statistical modeling and validated by CFD and wind tunnel data	"Low density waterfront locations are impacted heavily by trees. Medium-density locations should have permeable, spreading tree canopies. Instead of grass or shrubs, plant trees for shade and evapotranspiration in high density area. Even with a substantial drag effect, dense and columnar tree canopies may be acceptable in high-density urban environments."

Table A1. *Cont.*

Primary Focus	Authors	Title	Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design			Methodolog	Geographic Scale	Study Region	Aim	Relevant Findings
			Thermal Comfort	Energy Conservation	Health and Wellbeing	Renewable Energy and Grid Integration	Emission Reduction	Technology as an Enabler	Urban Morphology	Building Typology	Governance as Enabler					
	Ren et al. [23]	Creating breathing cities by adopting urban ventilation assessment and wind corridor plan–the implementation in Chinese cities	☆	□	☆	□	□	□	□	□	★	Spatial Analysis	City	East Asia	This paper reviews the urban ventilation corridor plan related activities in Chinese cities and present a case study of Chengdu to demonstrate local implementation of wind corridor planning and provide recommendations	"Four recommendations are given: the need for interdisciplinary collaboration and communication, the need for timely planning implementation and intervention, the need for accurate data collection and assembly, the need to consolidate spatial scale."
	Peng et al. [107]	Wind weakening in a dense high-rise city due to over nearly five decades of urbanization	☆	□	☆	□	□	□	★	□	□	CFD Modeling	Precinct	East Asia	This study applied CFD modeling with historical wind environments in Kowloon, Hong Kong from 1964 to 2010, to explore the influence of continuous urbanization on local wind condition	"The pedestrian level wind speed dropped by 67 percent in the examined urban areas as a result of ongoing urban expansion and building height increase. The wind speed may continue to decrease as a result of future developments outside the study area."

Table A1. *Cont.*

Primary Focus	Authors	Title	Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design			Methodolog	Geographic Scale	Study Region	Aim	Relevant Findings
			Thermal Comfort	Energy Conservation	Health and Wellbeing	Renewable Energy and Grid Integration	Emission Reduction	Technology as an Enabler	Urban Morphology	Building Typology	Governance as Enabler					
	Zhan et al. [112]	Sustainable strategy: Comprehensive computational approach for wind path planning in dense urban area	☆	□	□	□	□	□	★	□	☆	Spatial Analysis	City	East Asia	Introduces a comprehensive framework that assesses the urban heat environment and formulates urban wind paths.	"Two strategies that should be taken into urban planning: protect wind entrances, planning controls on spatial form of ventilation paths. The width and direction of the ventilation path and the height and configuration of buildings around the path are the main controllable indicators. Street features should be arranged in accordance with the wind direction to reduce wind obstruction."
	Liu et al. [57]	Disentangling the complex effects of socioeconomic, climatic, and urban form factors on air pollution: A case study of China	□	□	★	□	□	□	□	□	□	Statistical Analysis	City	East Asia	To understand the underlying patterns and drivers of air pollution in major cities in China	"Higher precipitation, higher wind speed, and higher temperatures were all negatively correlated with air pollution levels."

Table A1. *Cont.*

Primary Focus	Authors	Title	Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design			Methodolog	Geographic Scale	Study Region	Aim	Relevant Findings
			Thermal Comfort	Energy Conservation	Health and Wellbeing	Renewable Energy and Grid Integration	Emission Reduction	Technology as an Enabler	Urban Morphology	Building Typology	Governance as Enabler					
	Javanroodi et al. [40]	Impacts of urban morphology on reducing cooling load and increasing ventilation potential in hot-arid climate	□	★	□	□	□	□	★	✰	□	CFD Modeling	Building	Middle East	This study investigates the effects of urban morphology on cooling and ventilation potential by studying a high-rise building surrounded by different urban configurations during six warm months in Tehran	"Urban form, which leads to wind speed changes are important factor that affects building energy demand. Low rise and wider street do not increase wind speed and decrease cooling demand as expected."
	He et al. [105]	Effects of non-uniform and orthogonal breezeway networks on pedestrian ventilation in Singapore's high-density urban environments												Southeast Asia	Studies non-uniform and orthogonal wind networks in Singapore's central business district,	"Coarse and dense networks benefits ventilation. Orienting plan open areas to the prevailing wind improves natural ventilation. Road modifications affects pedestrian ventilation less often than open space inside the plots."

Table A1. *Cont.*

Primary Focus	Authors	Title	Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design			Methodolog	Geographic Scale	Study Region	Aim	Relevant Findings
			Thermal Comfort	Energy Conservation	Health and Wellbeing	Renewable Energy and Grid Integration	Emission Reduction	Technology as an Enabler	Urban Morphology	Building Typology	Governance as Enabler					
	Shaeri et al. [42]	Investigation of passive design strategies in a traditional urban neighborhood: A case study	★	☐	☐	☐	☐	☐	★	☆	☐	CFD Modeling	Precinct	Middle East	Explore the urban design elements that could moderate outdoor thermal conditions	"Alleys (passageways), open spaces, materials and colour of building façade and natural ventilation strategies are the best approach to cool cities using wind."
	An et al. [98]	Exploration of sustainable building morphologies for effective passive pollutant dispersion within compact urban environments	☐	☐	★	☐	☐	☐	★	★	☐	CFD Modeling	Street	East Asia	By quantitative evaluation of the levels of pollutant within both idealized urban areas and real cities through CFD modeling, this paper assesses the effectiveness of building design strategies to enhance air quality and ventilation within street canyons and the surroundings	"Controlling building height by placing lower buildings in front of taller buildings allows better ventilation. Site permeability lower than 20%, as measured by building coverage ratio leads to poor ventilation. Large arcade or 'dragon hole' integrated in buildings proposed as a design solution to improve ventilation."

Table A1. *Cont.*

Primary Focus	Authors	Title	Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design			Methodolog	Geographic Scale	Study Region	Aim	Relevant Findings
			Thermal Comfort	Energy Conservation	Health and Wellbeing	Renewable Energy and Grid Integration	Emission Reduction	Technology as an Enabler	Urban Morphology	Building Typology	Governance as Enabler					
	He et al. [115]	A parametric study of angular road patterns on pedestrian ventilation in high-density urban areas	✰	☐	☐	☐	☐	☐	★	☐	☐	Wind Tunnel CFD Modeling	Street	Southeast Asia	To understand how street orientation affects ventilation, more specifically, to establish relationships between road intersection angles and wind distribution	"Angular patterns more evenly transfer the horizontal flow than grid/orthogonal patterns. Upstream road segments should face the wind to increase incoming flow, while downstream segments should have modest inflow angles to balance downstream and lateral flow penetration."
	Li et al. [52]	Investigating the relationship between air pollution variation and urban form	☐	☐	★	☐	☐	☐	★	★	☐	Spatial Analysis	City	East Asia	Describe the air quality through pollutants and its spatial relation with urban form features in Shanghai	"Pollution concentrations are positively impacted by building heights and compactness. Optimization of wind corridors are proposed as the solution."

Table A1. *Cont.*

Primary Focus	Authors	Title	Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design			Methodolog	Geographic Scale	Study Region	Aim	Relevant Findings
			Thermal Comfort	Energy Conservation	Health and Wellbeing	Renewable Energy and Grid Integration	Emission Reduction	Technology as an Enabler	Urban Morphology	Building Typology	Governance as Enabler					
	Li et al. [60]	Impacts of wind fields on the distribution patterns of traffic emitted particles in urban residential areas	□	□	★	□	□	□	★	□	□	Field Study, CFD Modeling	Street	East Asia	Use field study of pollutants concentration and CFD modeling to understand building distribution and configuration effects on pollutant dispersion	"Orienting residential structures parallel to the primary wind direction might prevent pollutants from entering the plot. If the residential area is downwind of a road, the buildings should be oriented parallel to the primary wind direction in the district to decrease pollution deposition. Higher residential structures should be positioned on the windward side of the region to promote the early removal of air pollutants and reduce their direct penetration by wind."
	Zhou et al. [32]	Sea breeze cooling capacity and its influencing factors in a coastal city	□	□	□	□	□	□	★	★	□	Statistical Analysis	Precinct	Oceania	Quantify the cooling effects of sea breeze in central business district of Adelaide, Australia	"Sea breeze cooling capacity is negatively correlated with frontal area index and positively correlated with terrain ruggedness index. High rise buildings may reduce wind cooling effects."

Table A1. *Cont.*

Primary Focus	Authors	Title	Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design			Methodolog	Geographic Scale	Study Region	Aim	Relevant Findings
			Thermal Comfort	Energy Conservation	Health and Wellbeing	Renewable Energy and Grid Integration	Emission Reduction	Technology as an Enabler	Urban Morphology	Building Typology	Governance as Enabler					
	He et al. [116]	Enhancing urban ventilation performance through the development of precinct ventilation zones: A case study based on the Greater Sydney, Australia	☆	☐	☐	☐	☐	☐	★	☐	☆	Spatial Analysis	Precinct	Oceania	Developed the technique for the assessment of precinct ventilation in order to characterize urban surface structures for systematic research of local ventilation performance of Sydney	"The precinct ventilation zone concept was developed based on 'compactness + building height + street structure', from which 20 various precinct ventilation zone types were provided."
	Heusinger and Sailor [34]	Heat and Cold Roses of U.S. Cities: a New Tool for Optimizing Urban Climate	★	☐	☐	☐	☐	☐	☆	☐	☐	Climate Modeling	Building	North America	Developed a novel visualization approach that integrates wind and thermal index to determine optimal building and precinct design in 50 U.S cities	"Benchmarking wind flow characteristics is important for designing ventilation efficient built environments. A simplistic sample building configuration was provided which allows both ventilation cooling and thermal insulation from wind."

Table A1. *Cont.*

Primary Focus	Authors	Title	Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design			Methodolog	Geographic Scale	Study Region	Aim	Relevant Findings
			Thermal Comfort	Energy Conservation	Health and Wellbeing	Renewable Energy and Grid Integration	Emission Reduction	Technology as an Enabler	Urban Morphology	Building Typology	Governance as Enabler					
	Yang et al. [14]	Local climate zone ventilation and urban land surface temperatures: Towards a performance-based and wind-sensitive planning proposal in megacities	★	□	□	□	□	□	✰	★	□	Spatial	City	East Asia	Uses performance-based planning to assess the impact of urban morphology on local climate under different wind conditions in Shanghai	"In high density areas, high-rise buildings generate heat by obstructing wind. Limiting the height and compactness could improve urban heat island effects, alone with other strategies."
	Kaseb et al. [91]	A framework for pedestrian-level wind conditions improvement in urban areas: CFD simulation and optimization	✰	□	□	□	□	□	□	★	□	CFD Modeling Artificial Intelligence	Building	Middle East	Used a novel framework to evaluate optimization strategies to pedestrian wind environment in Tehran	"Large number of possible building height combination and plan area densities are assessed as influencing parameters on wind condition. Only wind direction was considered."

Table A1. *Cont.*

Primary Focus	Authors	Title	Wind in the Context of Urban Ventilation: Thermal Comfort	Wind in the Context of Urban Ventilation: Energy Conservation	Wind in the Context of Urban Ventilation: Health and Wellbeing	Wind in the Context of Urban Energy: Renewable Energy and Grid Integration	Wind in the Context of Urban Energy: Emission Reduction	Wind in the Context of Urban Energy: Technology as an Enabler	Wind in the Context of Urban Planning and Design: Urban Morphology	Wind in the Context of Urban Planning and Design: Building Typology	Wind in the Context of Urban Planning and Design: Governance as Enabler	Methodolog	Geographic Scale	Study Region	Aim	Relevant Findings
	He et al. [106]	Outdoor thermal environment of an open space under sea breeze: A mobile experience in a coastal city of Sydney, Australia	★	✫	✫	☐	☐	☐	☐	★	☐	Field Studies Statistical Modeling	Building	Oceania	Investigated the cooling effects of sea breeze on outdoor thermal environment with the consideration of built form in an open space of Sydney, Australia based on mobile measurement	"At larger open spaces, the wind cooling potential was more significant. While comparing to solar radiation, influence of wind is smaller. But effects on cooling are larger when background temperature is higher."
	He et al. [15]	Wind-sensitive urban planning and design: Precinct ventilation performance and its potential for local warming mitigation in an open midrise gridiron precinct	★	☐	☐	☐	☐	☐	★	☐	☐	Field Study, Statistical Analysis	Precinct	Oceania	To understand the effectiveness of wind cooling and associated urban morphological parameter in midrise precinct	"Wind ventilation exhibits significant potential in reducing urban heating. External metrological factors have larger effects on ventilation performance than urban morphological factors in midrise precinct."

Table A1. *Cont.*

Primary Focus	Authors	Title	Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design			Methodolog	Geographic Scale	Study Region	Aim	Relevant Findings
			Thermal Comfort	Energy Conservation	Health and Wellbeing	Renewable Energy and Grid Integration	Emission Reduction	Technology as an Enabler	Urban Morphology	Building Typology	Governance as Enabler					
	He et al. [28]	Relationships among local-scale urban morphology, urban ventilation, urban heat island and outdoor thermal comfort under sea breeze influence	★	□	□	□	□	□	★	□	□	Field Study, Statistical Analysis	Precinct	Oceania	Aim to understand the relationship between precinct morphology and precinct ventilation and its influence on UHIs and outdoor thermal comfort in a compact high-rise precinct	"Sea breeze could significantly mitigate urban heat by improving ventilation performance and increase relative humidity. Street orientation is not a critical factor for precinct level ventilation."
	He et al. [96]	Urban ventilation and its potential for local warming mitigation: A field experiment in an open low-rise gridiron precinct	★	□	□	□	□	□	★	○	□	Field Study, Statistical Analysis	Precinct	Oceania	Aim to understand the relationship between precinct morphology and precinct ventilation and its influence on UHIs and outdoor thermal comfort in a low-rise precinct	"Precinct ventilation performance varies significantly with external meteorological factors in low rise precinct. The influence of precinct morphological parameters became increasingly stronger following the order of open low-rise, open midrise and compact high-rise."

Table A1. *Cont.*

Primary Focus	Authors	Title	Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design			Methodolog	Geographic Scale	Study Region	Aim	Relevant Findings
			Thermal Comfort	Energy Conservation	Health and Wellbeing	Renewable Energy and Grid Integration	Emission Reduction	Technology as an Enabler	Urban Morphology	Building Typology	Governance as Enabler					
	Grunwald et al. [93]	Predicting urban cold-air paths using boosted regression trees	✰	□	□	□	□	□	★	○	□	Machine Learning	City	Europe	A machine learning technique, boosted regression trees (BRT), was used for estimating the spatial distribution of cold-air paths in three German cities	"The technique approved to be accurate. Three factors describing changes in surface elevation revealed largest effect on geographic distribution of cold-air paths: relative surface elevation, topographic position and topographic effects on airflow."
	Yang et al. [61]	Air pollution dispersal in high density urban areas: Research on the triadic relation of wind, air pollution, and urban form	□	□	★	□	□	□	★	□	□	CFD Modeling	Precinct	East Asia	Analyzed changes in wind velocity, direction, and air pollutant flow caused by changes in building height, volume, form, and density	"Corner zones surrounding high-rise buildings may generate pollution due to the high wind speed. Building height volume, layout, and orientation all significantly influence the flow and distribution of air pollution."

Table A1. *Cont.*

Primary Focus	Authors	Title	Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design			Methodolog	Geographic Scale	Study Region	Aim	Relevant Findings
			Thermal Comfort	Energy Conservation	Health and Wellbeing	Renewable Energy and Grid Integration	Emission Reduction	Technology as an Enabler	Urban Morphology	Building Typology	Governance as Enabler					
	Lee and Mak [102]	Effects of wind direction and building array arrangement on airflow and contaminant distributions in the central space of buildings	□	□	★	□	□	□	□	★	□	CFD Modeling	Building	East Asia	Using CFD modeling, the effects of incoming wind angles on wind velocity and pollutant dispersion within the center space of two L- and U-shaped building arrays were investigated	"L shaped buildings shows better wind speed and ventilation potential than U shaped buildings, highlighting the importance of minimizing building flow blockage."
	Song et al. [46]	Natural ventilation in London: Towards energy-efficient and healthy buildings	□	★	□	□	□	□	□	★	□	Wind Tunnel Modeling	City, Building	Europe	Quantified the impact of air pollution and noise pollution on the natural ventilation potential at both city scale and building scale in London	"Up to 37% more cooling energy saving if air and noise pollution were mitigated. At the building level. optimizing the relative location of window openings, more air can be drawn from the clean side and flushed out from the polluted side. Removing tall buildings or broadening road proved to reduce cooling energy through ventilation."

Table A1. *Cont.*

Primary Focus	Authors	Title	Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design			Methodolog	Geographic Scale	Study Region	Aim	Relevant Findings
			Thermal Comfort	Energy Conservation	Health and Wellbeing	Renewable Energy and Grid Integration	Emission Reduction	Technology as an Enabler	Urban Morphology	Building Typology	Governance as Enabler					
	Yang et al. [51]	Contribution of urban ventilation to the thermal environment and urban energy demand: Different climate background perspectives	☐	★	☐	☐	☐	☐	✩	☐	☐	Climate Modeling	City	East Asia	According to the frontal area index, the ventilation conditions of 31 major Chinese cities were grouped into four categories, and the natural ventilation impacts for cities in five climate zones were reported	"High frontal area index indicates poor ventilation. Most areas in the temperate climate zone with better ventilation has better thermal environment and lower energy consumption."
	Tang et al. [49]	Urban meteorological forcing data for building energy simulations	☐	★	☐	☐	☐	☐	☐	✩	☐	Statistical Analysis	Building	East Asia	Simulation of building energy consumption based on neighborhood climate	"Local wind speed has the largest impact on building energy load. Wind speed has higher impact on energy load at higher building levels."
	Wei [41]	Research on Reducing Carbon Consumption in Residential Community Spaces as Influenced by Microclimate Environments	☐	★	☐	☐	☐	☐	★	✩	☐	CFD	Precinct	East Asia	Examines the interaction link between spatial layouts and microclimate settings of typical residential communities in China and optimization strategies	"Incoherent spatial layout results in wind stagnation. Poor ventilation leads to higher temperature in summer when comparing to good ventilation areas. Uniform high-density layout comparing with hybrid layouts with reasonable building size and spacing."

Table A1. *Cont.*

Primary Focus	Authors	Title	Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design			Methodolog	Geographic Scale	Study Region	Aim	Relevant Findings
			Thermal Comfort	Energy Conservation	Health and Wellbeing	Renewable Energy and Grid Integration	Emission Reduction	Technology as an Enabler	Urban Morphology	Building Typology	Governance as Enabler					
	Pallares-Barbera et al. [36]	Grid orientation and natural ventilation in Cerdà's 1860 urban plan for Barcelona	☆	□	☆	□	□	□	★	○	□	Spatial	Precinct	Europe	Consistency analysis of the grid orientation and wind flow direction in Barcelona to demonstrate grid orientation ventilation potential	"In a temperate climate where both cooling and insulation are required, street orientation plays a major role on shaping air flow and ventilation. However, this gird form of Barcelona is difficult to replicate."
	Liu et al. [58]	Modeling the Impacts of City-Scale "Ventilation Corridor" Plans on Human Exposure to Intra-Urban PM2. 5 Concentrations	□	□	★	□	□	□	☆	□	☆	Climate Modeling	City	East Asia	To examine ventilation corridor impacts, efforts have been made to estimate the impact of ventilation corridor solutions in Shanghai's high density, diversified terrain	"Land use and building have a substantial effect on the ventilation effectiveness of wind corridors, which lowers the dispersion of pollutants. Roadway design and increase urban porosity is not as effective as expected."

Table A1. *Cont.*

Primary Focus	Authors	Title	Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design			Methodolog	Geographic Scale	Study Region	Aim	Relevant Findings
			Thermal Comfort	Energy Conservation	Health and Wellbeing	Renewable Energy and Grid Integration	Emission Reduction	Technology as an Enabler	Urban Morphology	Building Typology	Governance as Enabler					
	Loibl et al. [30]	Effects of Densification on Urban Microclimat: A Case Study for the City of Vienna	★	☐	☐	☐	☐	☐	★	☐	☐	Climate Modeling	Precinct	Europe	Assess the effects of densification on the urban climate of Vienna. The case study examined the potential possible consequences on wind environment and outdoor thermal comfort	"Although the wind is weaker in compact, high-density areas, the influence of blocked solar radiation on the thermal environment exceeds the impact of reduced wind. However, reduced air speed may exacerbate urban heat island effects."
	Lan et al. [109]	Improved urban heat island mitigation using bioclimatic redevelopment along an urban waterfront at Victoria Dockside, Hong Kong	★	☐	☐	☐	☐	☐	★	☐	☐	Climate Analysis	City	East Asia	To examine the synergistic mitigating impacts of redeveloped urban forms, ventilation corridors, and extensive vegetation on local microclimate and outdoor thermal comfort at an urban waterfront in Hong Kong	"The right use of mixed urban forms and ventilation corridors along waterfronts have the potential to allow winds to penetrate inner urbanized area even when the prevailing winds do not match the corridor's axis. The cooling effect is further enhanced by green belts."

Table A1. *Cont.*

Primary Focus	Authors	Title	Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design			Methodolog	Geographic Scale	Study Region	Aim	Relevant Findings
			Thermal Comfort	Energy Conservation	Health and Wellbeing	Renewable Energy and Grid Integration	Emission Reduction	Technology as an Enabler	Urban Morphology	Building Typology	Governance as Enabler					
	Peng et al. [53]	Urban ventilation of typical residential streets and impact of building form variation	☆	□	☆	□	□	□	★	☆	□	CFD Modeling	Street	East Asia	Investigates the ventilation performance of residential streets bounded by buildings of different and provide suggestions for designing urban streets	"Streets that face north-south have better ventilation than streets that face east-west. For EW-facing streets, avoid building parallel to the street. For NS-oriented streets is keep the buildings perpendicular to the street."
	Fang and Zhao [59]	Assessing the environmental benefits of urban ventilation corridors: A case study in Hefei, China	★	□	★	□	□	□	★	□	□	Spatial Analysis	City	East Asia	Using Hefei as an example, this study proposed a corridor construction model based on the ventilation resistance coefficient (VRC) and quantified and compared the environmental indicators for different corridor levels in order to comprehend the environmental benefits created	"Ventilation resistance coefficient, measured by surface roughness shows strong positive relation with thermal and pollutant dispersion on a macro level. Different wind corridor has intersection nodes where ventilation effects are highest."

Table A1. *Cont.*

Primary Focus	Authors	Title	Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design			Methodolog	Geographic Scale	Study Region	Aim	Relevant Findings
			Thermal Comfort	Energy Conservation	Health and Wellbeing	Renewable Energy and Grid Integration	Emission Reduction	Technology as an Enabler	Urban Morphology	Building Typology	Governance as Enabler					
	Wang et al. [25]	Identifying urban ventilation corridors through quantitative analysis of ventilation potential and wind characteristics	☆	☐	☆	☐	☐	☐	★	☐	☐	Spatial Analysis	City	East Asia	In this work, urban wind corridors were designed using a newly developed method that combines land surface temperature retrieval, GIS analysis, and meteorological data	"Water bodies, green fields and road network can act as ventilation corridors, while waterbodies and green fields provides largest thermal benefits. Road networks can work as supplement in high density environment where water bodies and green fields are unavailable."
	Zheng et al. [101]	Impact of building façade geometrical details on pollutant dispersion in street canyons	☐	☐	★	☐	☐	☐	☐	★	☐	CFD Modeling	Building	East Asia	This study examines the effect of building facade geometrical elements on the process of pollutant in long street canyons	"Building balconies can alter wind patterns in street canyons, especially windward balconies. Windward balconies prevent airflow from entering deep into the canyon, reducing wind speed at street level and increase pollutant concentration."

Table A1. *Cont.*

Primary Focus	Authors	Title	Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design			Methodolog	Geographic Scale	Study Region	Aim	Relevant Findings
			Thermal Comfort	Energy Conservation	Health and Wellbeing	Renewable Energy and Grid Integration	Emission Reduction	Technology as an Enabler	Urban Morphology	Building Typology	Governance as Enabler					
	Kwok et al. [27]	To what extent can urban ventilation features cool a compact built-up environment during a prolonged heatwave? A mesoscale numerical modeling study for Hong Kong	★	☐	☐	☐	☐	☐	★	☐	☐	Statistical Analysis	City	East Asia	Used novel modeling tools to validate proposed ventilation features. on mitigating urban heat	"Ventilation benefits are relatively localized and need for greater urban porosity. Alignment of street with prevailing winds and connecting open spaces improves ventilation performance."
	Li et al. [97]	Exploring urban space quantitative indicators associated with outdoor ventilation potential	☆	☐	☆	☐	☐	☐	★	☐	☐	CFD Modeling	Precinct	East Asia	This study explored the relationship between the sky view factor (SVF) and outdoor ventilation performance, considering the SVF as a quantitative measure of urban local environments	"SVF has correlation between ventilation condition but lesser than other factors such as building layouts, wind direction etc. Thus, SVF can indicate space openness, which is connected to greater wind conditions, but it can't reflect all impact of urban morphological factors on ventilation conditions."

Table A1. *Cont.*

Primary Focus	Authors	Title	Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design			Methodolog	Geographic Scale	Study Region	Aim	Relevant Findings
			Thermal Comfort	Energy Conservation	Health and Wellbeing	Renewable Energy and Grid Integration	Emission Reduction	Technology as an Enabler	Urban Morphology	Building Typology	Governance as Enabler					
	Son et al. [95]	Wind corridor planning and management strategies using cold air characteristics: The application in Korean cities	✰	☐	☐	☐	☐	☐	★	☐	☐	Climate Modeling	City	East Asia	The properties of local cold air created based on several geographical factors were investigated in three cities in Korea	"Uniform surface roughness or heights improves airflow. Airflow near water bodies and flat surface in cities are much better compared to other topography. Adopting of specific wind corridor are recommended to avoid blockage by urban land use."
	Maing [108]	Superblock transformation in Seoul Megacity: Effects of block densification on urban ventilation patterns	✰	☐	✰	☐	☐	☐	★	☐	☐	CFD Modeling	Precinct	East Asia	Investigates the growth and change in superblocks in Seoul between the 1980s and the 2020s, as well as the consequences on the urban ventilation environment	"Lack of open space, high site coverage ratio and discontinuous streets reduce wind speed. Tall building creates an inverted walling effect diverting the surface winds upward and away from the street level which reduces ventilation."

Table A1. *Cont.*

			Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design							
Primary Focus	**Authors**	**Title**	**Thermal Comfort**	**Energy Conservation**	**Health and Wellbeing**	**Renewable Energy and Grid Integration**	**Emission Reduction**	**Technology as an Enabler**	**Urban Morphology**	**Building Typology**	**Governance as Enabler**	**Methodolog**	**Geographic Scale**	**Study Region**	**Aim**	**Relevant Findings**
	Palusci et al. [22]	Impact of morphological parameters on urban ventilation in compact cities: The case of the Tuscolano-Don Bosco district in Rome	☆	☐	☆	☐	☐	☐	★	★	☐	CFD Modeling	Precinct	Europe	This study investigates the urban morphological parameters impact on ventilation, as measured by wind speed in Rome	"Building height's influence on wind speed is not as strong as plan area density. Suggests high permeability of plots."
Urban Wind Energy	Bahaj et al. [62]	Urban energy generation: Influence of micro-wind turbine output on electricity consumption in buildings	☐	☐	☐	☆	★	☐	☆	☐	☐	Spatial Analysis	City	Europe	This paper discusses the modeling of wind turbine installations in the United Kingdom and proposes a technique for assessing the appropriateness and economic viability of micro-wind turbines for residential use	"Micro-wind technology might boost home power output at the windiest sites and save more carbon emission at lower cost, comparing to PV system. Urban or suburban areas are unlikely to see a proliferation of these turbines due to turbulence and shadow effect. Feed-in tariff reduces payback times."

Table A1. *Cont.*

Primary Focus	Authors	Title	Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design			Methodolog	Geographic Scale	Study Region	Aim	Relevant Findings
			Thermal Comfort	Energy Conservation	Health and Wellbeing	Renewable Energy and Grid Integration	Emission Reduction	Technology as an Enabler	Urban Morphology	Building Typology	Governance as Enabler					
	Peel and Lloyd [122]	Positive Planning for Wind-Turbines in an Urban Context	☐	☐	☐	☐	☐	☆	☐	☐	★	Qualitative Analysis	City	Europe	Discuss the nature of the relationships between the government, the market, and the public in the development of urban wind-energy project	"Emphasized the necessity of well-thought-out urban planning strategies that consider the perspectives of all relevant parties."
	Sharpe [66]	Building mounted wind turbines on existing multi-storey housing	☐	☐	☐	☐	☐	★	☐	☐	☆	Statistical Analysis	Building	Europe	This study explores the usage of wind turbines in existing high-rise residences in a specific region. It covers two Glasgow initiatives and identifies obstacles and prospects for similar efforts abroad	"General manufacturers' reported data isn't robust enough to determine energy output. Manufacturers publish power curves are based on ideal locations and conditions. Limited data from monitored locations indicates lower-than-expected performance and marginal feasibility without grant aid."

Table A1. *Cont.*

Primary Focus	Authors	Title	Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design			Methodolog	Geographic Scale	Study Region	Aim	Relevant Findings
			Thermal Comfort	Energy Conservation	Health and Wellbeing	Renewable Energy and Grid Integration	Emission Reduction	Technology as an Enabler	Urban Morphology	Building Typology	Governance as Enabler					
	Mithraratne [63]	Roof-top wind turbines for microgeneration in urban houses in New Zealand	□	□	□	□	★	✩	□	□	□	Statistical Analysis	Building	Oceania	Life cycle assessment is used to analyze the overall energy and carbon emissions associated with deploying roof-top wind turbines in urban New Zealand residences	"Rooftop turbines are only feasible in limited locations and likely to support small part of the total electricity requirement of residences. To reduce general emission, transport and recycling of the turbine are consider carbon intensive."
	Walters and Walsh [64]	Examining the financial performance of micro-generation wind projects and the subsidy effect of feed-in tariffs for urban locations in the United Kingdom	□	□	□	□	□	✩	□	□	★	Statistical Analysis	City	Europe	Evaluate the financial aspects of 2010 UK feed in tariff in urban locations based on wind speed and project costs estimations	"The 2010 UK tariff level unlikely to boost urban commercial viability of wind turbines. The influence purchase behavior overall, including extra motives like as energy independence and environmental benefit remains difficult to assess, but from a financial standpoint, small wind turbines in urban areas seem to be a loss."

Table A1. *Cont.*

Primary Focus	Authors	Title	Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design			Methodolog	Geographic Scale	Study Region	Aim	Relevant Findings
			Thermal Comfort	Energy Conservation	Health and Wellbeing	Renewable Energy and Grid Integration	Emission Reduction	Technology as an Enabler	Urban Morphology	Building Typology	Governance as Enabler					
	Chong et al. [83]	Techno-economic analysis of a wind–solar hybrid renewable energy system with rainwater collection feature for urban high-rise application	☐	☐	☐	✰	☐	★	☐	☐	☐	Statistical Analysis	Building	Southeast Asia	This paper presents the technical and economic feasibility analysis of a novel guided vane wind turbine system with solar and rainwater collecting for energy generation	"The guided vane turbine overcomes low wind speed and can be place on high rise building rooftops. Estimated energy generation efficiency is much higher than conventional hybrid systems due to novel design."
	Evans et al. [119]	Urban wind power and the private sector: community benefits, social acceptance and public engagement	☐	☐	☐	✰	☐	☐	☐	☐	★	Qualitative Analysis	Building	Europe	Utilizing a case study of the building of wind turbines in two semi-urban areas of the United Kingdom, this research examines the effects of commercial urban wind projects on local populations	"Responses from the community to the ideas were complex and varied and could not be effectively captured by 'nimby' (not in my backyard) labelling. Climate change justification for turbines was considered 'greenwashing' by residents. Unrelated concerns correlate with local oppositions. Poor communication plays a part in obstructing the implementation of wind turbine schemes."

Table A1. *Cont.*

Primary Focus	Authors	Title	Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design			Methodolog	Geographic Scale	Study Region	Aim	Relevant Findings
			Thermal Comfort	Energy Conservation	Health and Wellbeing	Renewable Energy and Grid Integration	Emission Reduction	Technology as an Enabler	Urban Morphology	Building Typology	Governance as Enabler					
	Timmeren et al. [78]	Sustainable Urban Regeneration Based on Energy Balance	☐	☐	☐	★	✫	☐	☐	☐	☐	Qualitative Analysis	Precinct	Europe	A technology assessment of the use and integration of decentralized energy systems and storage devices in an urban renewal area in Rotterdam	"Load shifting in smart grids are considered as important as consumption and production in renewable energy management. Yet, wind turbines, which are legally allowed, are discovered to be excessively costly and less effective (without providing evidence)."
	Abohela et al. [89]	Effect of roof shape, wind direction, building height and urban configuration on the energy yield and positioning of roof mounted wind turbines	☐	☐	☐	✫	☐	☐	☐	★	☐	CFD Modeling	Building	Europe	Determine how different roof designs affect the energy output and the location of rooftop wind turbines to cover various building heights in various urban layouts under various wind directions	"Wind turbine on the roof should be mounted on buildings taller than the surrounding, with optimum roof designs in order to maximize energy yield, if an informed wind assessment above buildings' roofs is carried out."

Table A1. *Cont.*

Primary Focus	Authors	Title	Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design			Methodolog	Geographic Scale	Study Region	Aim	Relevant Findings
			Thermal Comfort	Energy Conservation	Health and Wellbeing	Renewable Energy and Grid Integration	Emission Reduction	Technology as an Enabler	Urban Morphology	Building Typology	Governance as Enabler					
	Millward-Hopkins et al. [72]	Assessing the potential of urban wind energy in a major UK city using an analytical model	□	□	□	★	□	□	□	✰	□	Spatial Analysis	City	Europe	Testing remoting sensing methodology using geometric data describing building roof shapes in addition to heights, to estimate surface aerodynamic parameters and locating viable sites energy potential of Leeds	"The finding indicates the possibility of city-scale wind speed estimation with basic meteorological dataset. Thousands of viable sites with all year minimum wind speed for turbine operations are located, including within the complex city center. However, residential areas are not suitable."
	Drew et al. [71]	Estimating the potential yield of small wind turbines in urban areas: A case study for Greater London, UK	□	□	□	★	□	□	★	□	□	Spatial Analysis	City	Europe	At a height typical of current small wind turbine installations, this study performs general estimation of the annual mean wind speed across Greater London, using basic surface roughness measured by building heights	"Only about a third of London is suitable for the installation of wind turbines. There are only a small number of locations within 10 kilometers of the city center, and the majority are located outside of the city. With a more accurate site estimate, more convenient locations near the city's core might be discovered."

Table A1. *Cont.*

			Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design							
Primary Focus	**Authors**	**Title**	**Thermal Comfort**	**Energy Conservation**	**Health and Wellbeing**	**Renewable Energy and Grid Integration**	**Emission Reduction**	**Technology as an Enabler**	**Urban Morphology**	**Building Typology**	**Governance as Enabler**	**Methodolog**	**Geographic Scale**	**Study Region**	**Aim**	**Relevant Findings**
	Bourne et al. [117]	The economic assessment of micro wind turbines for South Australia	☐	☐	☐	✰	☐	☐	☐	☐	✰	Statistical Analysis	City	Oceania	The study presents a method to find productive places utilizing net present value (NPV). By simulating wind conditions with a 2-parameter Weibull function to assure a turbine's economic feasibility	"The findings show that supplementing a fed in tariff is more effective than discounting the initial capital invested by households to expand the urban wind turbine economic feasibility."
	Scott et al. [120]	Evaluating the cumulative impact problem in spatial planning: A case study of wind turbines in Aberdeenshire, UK	☐	☐	☐	✰	☐	☐	☐	☐	★	Qualitative Analysis	City	Europe	This article examines how cumulative effect is handled within the Scottish planning system through a case study centered on small-scale wind development, including assessments of planning applications and interviews with key stakeholders	"Wind turbine projects in this study possess major guidance, data, and methodological deficiencies leading to a disjuncture between judging applications on their own merit vs broader strategic and long-term considerations. More social learning and dialogue are recommended."

Table A1. *Cont.*

Primary Focus	Authors	Title	Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design			Methodolog	Geographic Scale	Study Region	Aim	Relevant Findings
			Thermal Comfort	Energy Conservation	Health and Wellbeing	Renewable Energy and Grid Integration	Emission Reduction	Technology as an Enabler	Urban Morphology	Building Typology	Governance as Enabler					
	Emejeamara et al. [88]	Urban wind: Characterisation of useful gust and energy capture	☐	☐	☐	☐	☐	★	☐	☐	☐	Field Study, Statistical Analysis	Building	Europe	This paper addresses the potential importance of harvesting wind turbulence by using gust tracking technologies using high resolution measurements at two urban roof-top locations	"Uniform wind speed is not the only consideration in predicting wind energy potential. Turbulent intensity, which is the sudden increase of wind speed, if predicted correctly could be harvested for additional energy."
	Culotta et al. [118]	Small wind technology diffusion in suburban areas of Sicily	☐	☐	☐	★	☐	✰	☐	☐	✰	Statistical Analysis	City	Europe	Analyses of wind turbine performance in relation to different parameters	"Wind turbine performance are heavily dependent on location and requires significant government incentives."
	Mohammadnezami et al. [80]	Meeting the electrical energy needs of a residential building with a wind-photovoltaic hybrid system	☐	☐	☐	★	✰	☐	☐	☐	☐	Statistical Analysis	Building	Middle East	Determine the optimal hybrid system for satisfying a residential building's electrical energy demands. The hybrid system consists of a wind turbine, a photovoltaic system, and a battery for energy storage in Tehran	"The cost of the hybrid system design is 78% cheaper than that of a wind turbine system and 34% cheaper than that of a photovoltaic system."

Table A1. *Cont.*

			Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design							
Primary Focus	**Authors**	**Title**	**Thermal Comfort**	**Energy Conservation**	**Health and Wellbeing**	**Renewable Energy and Grid Integration**	**Emission Reduction**	**Technology as an Enabler**	**Urban Morphology**	**Building Typology**	**Governance as Enabler**	**Methodolog**	**Geographic Scale**	**Study Region**	**Aim**	**Relevant Findings**
	Adam et al. [68]	Methodologies for city-scale assessment of renewable energy generation potential to inform strategic energy infrastructure investment	☐	☐	☐	✰	✰	☐	☐	☐	☐	Spatial Analysis	City	Europe	Rapid methodology to calculate renewable energy generation potential and economic performance in Leeds, UK	"Long term average wind speeds are predicted using a logarithmic vertical wind profile. The Methodology is not precise but allows large city level asset holders to make quick strategic investment decisions across their entire portfolio."
	Cooney et al. [86]	Performance characterisation of a commercial-scale wind turbine operating in an urban environment, using real data	☐	☐	☐	✰	☐	✰	☐	☐	☐	Statistical Analysis	Building	Europe	This study provides a performance characterization of a small wind turbine in Irish university campus with data measured over one yea, using Weibull distribution model	"While most of times the turbine works as intended, results suggest there are inconsistencies that show how real-world operation can differ from modeling and testing. Most cost is expended on installation thus operation and maintenance are few means to reduce cost."

Table A1. *Cont.*

Primary Focus	Authors	Title	Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design			Methodolog	Geographic Scale	Study Region	Aim	Relevant Findings
			Thermal Comfort	Energy Conservation	Health and Wellbeing	Renewable Energy and Grid Integration	Emission Reduction	Technology as an Enabler	Urban Morphology	Building Typology	Governance as Enabler					
	Futcher et al. [47]	Creating sustainable cities one building at a time: Towards an integrated urban design framework	☆	☆	☆	☆	☆	☐	☆	☆	★	Qualitative Analysis	City	Europe	The study focuses on access to sunlight and wind, as well as the broader consequences of priorities individual buildings above the surrounding urban landscape	“Demonstrate the limitations of existing building-scale energy sustainability analyses in urban environments. Impacts are strongest when buildings are close together and are most pronounced when towering structures are introduced into a low-lying urban area. Highlights the needs for integrated framework.”
	Lee et al. [82]	Renewable energy potential by the application of a building integrated photovoltaic and wind turbine system in global urban areas	☐	☐	☐	★	☐	☐	☐	☐	☐	Statistical Analysis	City	Worldwide	This study evaluated the worldwide utilization potential of a building-integrated photovoltaic and wind turbine system that may be fitted to a building’s exterior in urban areas	“Wind direction varies by season and climate thus careful consideration and installation are required. Wind energy system save up to 0.8% to 26.5 % of building energy.”

Table A1. *Cont.*

Primary Focus	Authors	Title	Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design			Methodolog	Geographic Scale	Study Region	Aim	Relevant Findings
			Thermal Comfort	Energy Conservation	Health and Wellbeing	Renewable Energy and Grid Integration	Emission Reduction	Technology as an Enabler	Urban Morphology	Building Typology	Governance as Enabler					
	Wang et al. [69]	Cross indicator analysis between wind energy potential and urban morphology	☐	☐	☐	☆	☐	☐	★	☆	☐	CFD Modeling	City	Europe	This research analyzes the link between urban wind energy potential and various urban tissues to encourage urban wind energy development	"Urban density and building intensity morphological parameters (floor area ratio, volume, height, porosity) has the highest impact on wind capacity. Rooftops of tall buildings are suggested in most city centers."
	Kumar et al. [67]	A critical review of vertical axis wind turbines for urban applications	☐	☐	☐	☐	☐	★	☐	☐	☐	Literature Review	City	Europe	Presents findings on VAWT from government and presents the scope and constraints of VAWT development. The study also outlines commercial VAWT efforts worldwide	"The focus of VAWT research was on the aerodynamics of airfoil, modeling, design efficacy in unsteady winds, project feasibility, self-start capabilities, and grid system integration. The low acceptability of VAWTs is owing to the unavailability of exact resource evaluation methods and the lack of comprehensive, dependable long-term performance data."

Table A1. *Cont.*

Primary Focus	Authors	Title	Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design			Methodolog	Geographic Scale	Study Region	Aim	Relevant Findings
			Thermal Comfort	Energy Conservation	Health and Wellbeing	Renewable Energy and Grid Integration	Emission Reduction	Technology as an Enabler	Urban Morphology	Building Typology	Governance as Enabler					
	Elbakheit [74]	A framework towards enhanced sustainable systems integration into tall buildings design	□	☆	□	☆	□	□	□	★	□	Qualitative Analysis	Building	Middle East	Examines methods to integrate passive and active renewable energy technologies and systems, green and sustainability measures into tall building's design	"Improving ventilation and wind energy capture on site through architectural integration, either on the roof or facades greatly improves energy performance of tall building in combination with other techniques and renewable sources."
	Broughel and Hampl [121]	Community financing of renewable energy projects in Austria and Switzerland: Profiles of potential investors	□	□	□	□	□	☆	□	□	★	Qualitative Analysis	City	Europe	Examines the influence of socio-demographic and socio-psychological factors on the willingness of individuals to invest in community renewable energy initiatives	"Positive attitudes and perceptions towards renewable energy have a substantial effect on investment intent. A portion of investors are receptive to the presence of wind energy facilities in their neighborhoods, whereas a considerable number of potential investors are apprehensive."

Table A1. *Cont.*

Primary Focus	Authors	Title	Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design			Methodolog	Geographic Scale	Study Region	Aim	Relevant Findings
			Thermal Comfort	Energy Conservation	Health and Wellbeing	Renewable Energy and Grid Integration	Emission Reduction	Technology as an Enabler	Urban Morphology	Building Typology	Governance as Enabler					
	Micallef and Van Bussel [85]	A review of urban wind energy research: aerodynamics and other challenges	□	□	□	★	□	★	□	✰	✰	Literature Review	N/A	N/A	Highlights the advancement on the study of wind and turbine engineering on exploiting wind energy in cities	"The current study in urban wind energy resources focuses on engineering approaches for determining wind statistics at specific areas of interest, mainly roof tops. CFD models have been used to study building forms and their aerodynamic effects. VAWT is the most prevalent turbine design, however turbulence requires improvement. Wind energy research must become more synergistic."

Table A1. *Cont.*

Primary Focus	Authors	Title	Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design			Methodolog	Geographic Scale	Study Region	Aim	Relevant Findings
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	Rodriguez-Hernandez et al. [87]	Techno-economic feasibility study of small wind turbines in the Valley of Mexico metropolitan area	□	□	□	☆	☆	□	□	□	□	Statistical Analysis	City	North America	This research created a system for analyzing the technical and economic viability of small wind turbines in Mexico by choosing and analyzing three years' worth of accessible wind data	"Limited suitable sites were reported due to low wind speed across study region. When turbine performs normally, the benefits can be expected both economic and environmental. Turbine nominal power could be lower than labelled. Further observation is needed to predict actual turbine performance."
	Teschner and Alterman [123]	Preparing the ground: Regulatory challenges in siting small-scale wind turbines in urban areas	□	□	□	□	□	☆	□	□	★	Qualitative Analysis	City	Europe	The primary objective of this paper is to investigate various planning approaches for small urban wind turbines.	The findings show that incorporating a new technology into a municipality demands a change in both officials and inhabitants' mindsets. Effective regulatory frameworks may need strategic thinking, an experimental approach, and the ability to learn from cross-national comparative experiences.

Table A1. *Cont.*

Primary Focus	Authors	Title	Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design			Methodolog	Geographic Scale	Study Region	Aim	Relevant Findings
			Thermal Comfort	Energy Conservation	Health and Wellbeing	Renewable Energy and Grid Integration	Emission Reduction	Technology as an Enabler	Urban Morphology	Building Typology	Governance as Enabler					
	Anup et al. [70]	Urban wind conditions and small wind turbines in the built environment: A review	☐	☐	☐	☐	☐f	★	☐	✰	☐	Literature Review	N/A	N/A	This paper looks at the different studies that have been done on the use of small wind turbine technology in the built environment. The goal is to understand the characteristics of incoming wind, how they function, and the knowledge gap	"Shape of buildings/roof pitches has influence on wind turbine location Airflow turbulence has strong impact on performance. Mounting the SWTs at a height 50% above the building height can help minimize the influence of turbulence. The current wind standard underestimates urban wind conditions and does not consider the dynamism of urban wind. Crucial to have more methodology."

Table A1. *Cont.*

Primary Focus	Authors	Title	Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design			Methodolog	Geographic Scale	Study Region	Aim	Relevant Findings
			Thermal Comfort	Energy Conservation	Health and Wellbeing	Renewable Energy and Grid Integration	Emission Reduction	Technology as an Enabler	Urban Morphology	Building Typology	Governance as Enabler					
	Tasneem et al. [65]	An analytical review on the evaluation of wind resource and wind turbine for urban application: Prospect and challenges	☐	☐	☐	☐	☐	★	☐	☐	☐	Literature Review	N/A	N/A	Highlights the present stats of urban wind energy technology and its commercial and environmental aspects	"Commercial turbine is either roof mounted or integrated within buildings. Savonius and Darrieus VAWT are suitable for small scale urban usage. Savonius turbines are more suitable for domestic uses due to low cut in wind speed. Darrieus VAWT suitable for large urban scale usage. Environmental impacts include biodiversity, visual noise and vibration."
	Shiraz et al. [76]	Wind power potential assessment of roof mounted wind turbines in cities	☐	☐	☐	☐	☐	★	★	☐	☐	CFD Modeling	Building	North America	Evaluates performance and energy output of roof mounted wind turbines in real urban environments using novel methodologies	High density site leads to low energy production even if the turbine is placed at a much higher altitude. For low density sites, the wind is less affected by surrounding buildings therefore the turbines perform better.

Table A1. *Cont.*

Primary Focus	Authors	Title	Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design			Methodolog	Geographic Scale	Study Region	Aim	Relevant Findings
			Thermal Comfort	Energy Conservation	Health and Wellbeing	Renewable Energy and Grid Integration	Emission Reduction	Technology as an Enabler	Urban Morphology	Building Typology	Governance as Enabler					
	Abdou et al. [43]	Multi-objective optimization of passive energy efficiency measures for net-zero energy building in Morocco	☐	★	☐	☆	★	☐	☐	★	☐	Statistical Analysis	Building	Africa	Evaluates the feasibility of reaching net-zero energy buildings in the Moroccan housing stock by integrating architectural energy efficiency methods with on side energy generation	"Building envelope with high window to wall ratio has strong association with lower energy consumption. PV system is the most efficient. Hybrid energy system cost lower than wind turbine system."
	Higgins and Stathopoulos [90]	Application of artificial intelligence to urban wind energy	☐	☐	☐	☐	☐	★	☐	☆	☐	CFD Modeling. Wind Tunnel. Artificial Intelli-gence	Building	North America	Generate an urban wind database using wind tunnel experiments and CFD models and use artificial intelligence (AI) tools to predict wind energy potential.	"By comparing with wind tunnel results, the AI tool was able to predict the modification of urban geometry on wind speed with high accuracy. Thus, useful in the process of assessing turbine placement locations."

Table A1. *Cont.*

Primary Focus	Authors	Title	Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design			Methodolog	Geographic Scale	Study Region	Aim	Relevant Findings
			Thermal Comfort	Energy Conservation	Health and Wellbeing	Renewable Energy and Grid Integration	Emission Reduction	Technology as an Enabler	Urban Morphology	Building Typology	Governance as Enabler					
	Juan et al. [73]	Numerical assessments of wind power potential and installation arrangements in realistic highly urbanized areas	☐	☐	☐	☆	☐	☐	☐	★	☐	CFD Modeling. Field Study	Building	East Asia	Assessment of urban wind energy potential of multiple realistic compact high rises building in Hong Kong. Validating CFD with onsite measurement	"Before turbine selection, location suability analysis must be conducted and validated. Roof and building geometry, upstream obstacles, parallel building and complex has impact on wind energy potential. The final positions for the installation of the turbines may be determined by measuring the level distances from the rooftop sidewalls and the heights above the rooftops."

Table A1. *Cont.*

Primary Focus	Authors	Title	Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design			Methodolog	Geographic Scale	Study Region	Aim	Relevant Findings
			Thermal Comfort	Energy Conservation	Health and Wellbeing	Renewable Energy and Grid Integration	Emission Reduction	Technology as an Enabler	Urban Morphology	Building Typology	Governance as Enabler					
	Juan et al. [75]	Impacts of urban morphology on improving urban wind energy potential for generic high-rise building arrays	□	□	□	☆	□	□	★	★	□	CFD Modeling	Building	East Asia	The primary objective of this study is to fill in the gaps in knowledge on the impacts of urban morphology in dense, high-rise urban settings on enhancing urban wind energy harvest	"Decreasing plot plan area density reduces the unacceptable turbulence areas with relatively higher wind power density on the roof. Round corners can produce elevated power densities than sharp corners beside the building, even under unfavorable wind flow. Straight line building layout is better than standalone layouts."
	Ruiz et al. [103]	Aerodynamic design optimization of ducted openings through high-rise buildings for wind energy harvesting	□	□	□	□	□	★	□	★	□	CFD Modeling	Building	N/A	CFD is used to optimize two important design factors that can improve the wind energy performance of ducted openings in high-rise structures. The study aims to add knowledge into BIWT research.	"Increasing the radius of a building's duct opening has limited influence on wind speed. Filleting the duct's sharp edge increases wind velocity. Combining a larger radius with filleting produces the greatest wind speed."

Table A1. *Cont.*

Primary Focus	Authors	Title	Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design			Methodolog	Geographic Scale	Study Region	Aim	Relevant Findings
			Thermal Comfort	Energy Conservation	Health and Wellbeing	Renewable Energy and Grid Integration	Emission Reduction	Technology as an Enabler	Urban Morphology	Building Typology	Governance as Enabler					
	Wilke et al. [81]	How Much Can Small-Scale Wind Energy Production Contribute to Energy Supply in Cities? A Case Study of Berlin	□	□	□	★	★	□	□	□	✰	Statistical Analysis	City	Europe	Addresses the possibility of urban wind energy generation with small wind turbines, using Berlin as an example, and establishes a data selection framework for economic feasibility	"Multiple wind turbines installed on suitable buildings can greatly contribute to the energy requirements of houses but cannot satisfy the total demand. Economic assessment highly advises the self-consumption of generated power by individual household (non-economical fit in tariff) The findings indicate that while the development of small wind turbines should continue to be supported, the importance of hybrid energy system in urban environments remains."

Table A1. *Cont.*

			Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design							
Primary Focus	**Authors**	**Title**	**Thermal Comfort**	**Energy Conservation**	**Health and Wellbeing**	**Renewable Energy and Grid Integration**	**Emission Reduction**	**Technology as an Enabler**	**Urban Morphology**	**Building Typology**	**Governance as Enabler**	**Methodolog**	**Geographic Scale**	**Study Region**	**Aim**	**Relevant Findings**
	Hachem-Vermette and Singh [79]	Analysis of Urban Energy Resources to Achieve Net-Zero Energy Neighborhoods	☐	☐	☐	✰	★	☐	☐	☐	☐	Statistical Analysis	Precinct	North America	Finding the best mix of renewable energy sources for different types and designs of building clusters in a northern city's neighborhood energy system	"Limited instalment of wind turbine win combination of solar panels could fulfill the electricity demands but not thermal demands. Other solar devices are needed to reduce the number of turbines."
	Sibilla [44]	Developing a process-oriented approach towards Positive Energy Blocks: the wind-analysis contribution	☐	★	☐	✰	★	☐	☐	✰	☐	CFD Modeling	Building	Europe	A case study involving three public school building in Rome. Illustrating a preliminary step using wind to orient strategic design solution in creating positive energy blocks (PEB)	"Wind form index (building influence on wind), wind thermal-loss index (wind speed influence on temperature) and wind energy production (minimum wind speed influence on energy production) index were developed. The study highlights the needs for relevant benchmark in decision marking for PEBs. Wind energy is limited but can be combine with solar."

Table A1. *Cont.*

Primary Focus	Authors	Title	Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design			Methodolog	Geographic Scale	Study Region	Aim	Relevant Findings
			Thermal Comfort	Energy Conservation	Health and Wellbeing	Renewable Energy and Grid Integration	Emission Reduction	Technology as an Enabler	Urban Morphology	Building Typology	Governance as Enabler					
	Manco et al. [77]	Innovative renewable technology integration for nearly zero-energy buildings within the Re-cognition project	□	□	□	★	✩	✩	★	□	□	Statistical Analysis	Building	Europe	Formulation, design, and operation optimization of an integrated multi-energy system comprised of conventional and novel renewable technologies are proposed in four case studies	"Turbine electricity was to support the operation of other renewable devices and energy system operation. Optimization strategies provide significant benefit in terms of cost and emission. VAWT may not be guarantee in other studies."
	Dai et al. [114]	Impact of corner modification on wind characteristics and wind energy potential over flat roofs of tall building	□	□	□	✩	□	□	□	★	□	CFD Modeling	Building	N/A	The effects of corner modifications and wind angle on wind energy potential were investigated	"Due to the high velocity (more energy), minimal turbulence (little wind turbine fatigue loads), and low installation height, a rounded roof was discovered to be appropriate for the installation of wind turbines."

Table A1. *Cont.*

Primary Focus	Authors	Title	Wind in the Context of Urban Ventilation			Wind in the Context of Urban Energy			Wind in the Context of Urban Planning and Design			Methodolog	Geographic Scale	Study Region	Aim	Relevant Findings
			Thermal Comfort	Energy Conservation	Health and Wellbeing	Renewable Energy and Grid Integration	Emission Reduction	Technology as an Enabler	Urban Morphology	Building Typology	Governance as Enabler					
	Wang et al. [92]	Urban form study for wind potential development	☐	☐	☐	☆	☐	☐	☐	★	☐	CFD Modeling	Building	East Asia	Fourteen typical urban forms in Beijing city were selected and analyzed with nine relevant urban morphology parameters to analyze wind energy production potential	"Higher plot ratios and mean aspect ratios increase wind potential density per site area. Higher building height means more wind per roof area. To increase wind potential over roofs, use a 45° building arrangement with inlet wind direction and round-angle corners. Local wind dispersion has a less influence on wind energy potential comparing to built environments with varied urban morphology factors."
	Koller et al. [84]	Resource Management as Part of Sustainable Urban District Development	☐	☐	☐	☆	☐	☐	☐	☐	★	Qualitative Analysis	Precinct	Europe	Understanding the impacts that urban districts have on the resources of land and material flows, as well as the resulting impacts on urban green spaces and energy issues	"Wind, as an urban resource should be considered in the usage of other resources (e.g., land, solar or water). As unoptimized usage could leads to conflicting goals."

References

1. Perveen, S.; Kamruzzaman, M.; Yigitcanlar, T. Developing policy scenarios for sustainable urban growth management: A Delphi approach. *Sustainability* **2017**, *9*, 1787. [CrossRef]
2. Yigitcanlar, T. *Sustainable Urban and Regional Infrastructure Development: Technologies, Applications and Management*; IGI Global: Hershey, PA, USA, 2010.
3. Dizdaroglu, D.; Yigitcanlar, T.; Dawes, L. A micro-level indexing model for assessing urban ecosystem sustainability. *Smart Sustain. Built Environ.* **2012**, *1*, 291–315. [CrossRef]
4. Goonetilleke, A.; Yigitcanlar, T.; Ayoko, G.A.; Egodawatta, P. *Sustainable Urban Water Environment: Climate, Pollution and Adaptation*; Edward Elgar: Cheltenham, UK, 2014.
5. Metaxiotis, K.; Carrillo, F.J.; Yigitcanlar, T. *Knowledge-Based Development for Cities and Societies: Integrated Multi-Level Approaches*; IGI Global: Hershey, PA, USA, 2010.
6. Lopes, A.; Saraiva, J.; Alcoforado, M.J. Urban boundary layer wind speed reduction in summer due to urban growth and environmental consequences in Lisbon. *Environ. Model. Softw.* **2011**, *26*, 241–243. [CrossRef]
7. Yigitcanlar, T.; Cugurullo, F. The sustainability of artificial intelligence: An urbanistic viewpoint from the lens of smart and sustainable cities. *Sustainability* **2020**, *12*, 8548. [CrossRef]
8. Pasqualetti, M.J. Wind power: Obstacles and opportunities. *Environ. Sci. Policy Sustain. Dev.* **2004**, *46*, 22–38. [CrossRef]
9. da Graça, G.C.; Linden, P. Ten questions about natural ventilation of non-domestic buildings. *Build. Environ.* **2016**, *107*, 263–273. [CrossRef]
10. Mostafaeipour, A.; Sedaghat, A.; Dehghan-Niri, A.; Kalantar, V. Wind energy feasibility study for city of Shahrbabak in Iran. *Renew. Sustain. Energy Rev.* **2011**, *15*, 2545–2556. [CrossRef]
11. Blocken, B.; Carmeliet, J. Pedestrian wind environment around buildings: Literature review and practical examples. *J. Therm. Envel. Build. Sci.* **2004**, *28*, 107–159. [CrossRef]
12. Stathopoulos, T.; Alrawashdeh, H.; Al-Quraan, A.; Blocken, B.; Dilimulati, A.; Paraschivoiu, M.; Pilay, P. Urban wind energy: Some views on potential and challenges. *J. Wind Eng. Ind. Aerodyn.* **2018**, *179*, 146–157. [CrossRef]
13. Palusci, O.; Cecere, C. Urban Ventilation in the Compact City: A Critical Review and a Multidisciplinary Methodology for Improving Sustainability and Resilience in Urban Areas. *Sustainability* **2022**, *14*, 3948. [CrossRef]
14. Yang, J.; Jin, S.; Xiao, X.; Jin, C.; Xia, J.; Li, X.; Wang, S. Local climate zone ventilation and urban land surface temperatures: Towards a performance-based and wind-sensitive planning proposal in megacities. *Sustain. Cities Soc.* **2019**, *47*, 101487. [CrossRef]
15. He, B.-J.; Ding, L.; Prasad, D. Wind-sensitive urban planning and design: Precinct ventilation performance and its potential for local warming mitigation in an open midrise gridiron precinct. *J. Build. Eng.* **2020**, *29*, 101145. [CrossRef]
16. Moher, D.; Shamseer, L.; Clarke, M.; Ghersi, D.; Liberati, A.; Petticrew, M.; Shekelle, P.; Stewart, L.A. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. *Syst. Rev.* **2015**, *4*, 1. [CrossRef]
17. Cortese, T.T.P.; Almeida, J.F.S.d.; Batista, G.Q.; Storopoli, J.E.; Liu, A.; Yigitcanlar, T. Understanding Sustainable Energy in the Context of Smart Cities: A PRISMA Review. *Energies* **2022**, *15*, 2382. [CrossRef]
18. Mongeon, P.; Paul-Hus, A. The journal coverage of Web of Science and Scopus: A comparative analysis. *Scientometrics* **2016**, *106*, 213–228. [CrossRef]
19. Degirmenci, K.; Desouza, K.C.; Fieuw, W.; Watson, R.T.; Yigitcanlar, T. Understanding policy and technology responses in mitigating urban heat islands: A literature review and directions for future research. *Sustain. Cities Soc.* **2021**, *70*, 102873. [CrossRef]
20. Ding, C.; Zhao, X. Urbanization in Japan, South Korea, and China: Policy and reality. In *The Oxford Handbook of Urban Economics and Planning*; Brooks, N., Donaghy, K., Knaap, G.J., Eds.; Oxford Academic: Oxford, UK, 2012; pp. 906–931.
21. Tan, Y.; Xu, H.; Zhang, X. Sustainable urbanization in China: A comprehensive literature review. *Cities* **2016**, *55*, 82–93. [CrossRef]
22. Palusci, O.; Monti, P.; Cecere, C.; Montazeri, H.; Blocken, B. Impact of morphological parameters on urban ventilation in compact cities: The case of the Tuscolano-Don Bosco district in Rome. *Sci. Total Environ.* **2022**, *807*, 150490. [CrossRef]
23. Ren, C.; Yang, R.; Cheng, C.; Xing, P.; Fang, X.; Zhang, S.; Wang, H.; Shi, Y.; Zhang, X.; Kwok, Y.T.; et al. Creating breathing cities by adopting urban ventilation assessment and wind corridor plan—The implementation in Chinese cities. *J. Wind Eng. Ind. Aerodyn.* **2018**, *182*, 170–188. [CrossRef]
24. Taleghani, M.; Kleerekoper, L.; Tenpierik, M.; van den Dobbelsteen, A. Outdoor thermal comfort within five different urban forms in the Netherlands. *Build. Environ.* **2015**, *83*, 65–78. [CrossRef]
25. Wang, W.; Wang, D.; Chen, H.; Wang, B.; Chen, X. Identifying urban ventilation corridors through quantitative analysis of ventilation potential and wind characteristics. *Build. Environ.* **2022**, *214*, 108943. [CrossRef]
26. Stathopoulos, T.; Wu, H.; Zacharias, J. Outdoor human comfort in an urban climate. *Build. Environ.* **2004**, *39*, 297–305. [CrossRef]
27. Kwok, Y.T.; de Munck, C.; Lau, K.K.-L.; Ng, E. To what extent can urban ventilation features cool a compact built-up environment during a prolonged heatwave? A mesoscale numerical modelling study for Hong Kong. *Sustain. Cities Soc.* **2022**, *77*, 103541. [CrossRef]
28. He, B.-J.; Ding, L.; Prasad, D. Relationships among local-scale urban morphology, urban ventilation, urban heat island and outdoor thermal comfort under sea breeze influence. *Sustain. Cities Soc.* **2020**, *60*, 102289. [CrossRef]
29. Berardi, U.; Wang, Y. The Effect of a Denser City over the Urban Microclimate: The Case of Toronto. *Sustainability* **2016**, *8*, 822. [CrossRef]

30. Loibl, W.; Vuckovic, M.; Etminan, G.; Ratheiser, M.; Tschannett, S.; Österreicher, D. Effects of Densification on Urban Microclimate—A Case Study for the City of Vienna. *Atmosphere* **2021**, *12*, 511. [CrossRef]
31. Peng, C.; Ming, T.; Cheng, J.; Wu, Y.; Peng, Z.-R. Modeling Thermal Comfort and Optimizing Local Renewal Strategies—A Case Study of Dazhimen Neighborhood in Wuhan City. *Sustainability* **2015**, *7*, 3109–3128. [CrossRef]
32. Zhou, Y.; Guan, H.; Huang, C.; Fan, L.; Gharib, S.; Batelaan, O.; Simmons, C. Sea breeze cooling capacity and its influencing factors in a coastal city. *Build. Environ.* **2019**, *166*, 106408. [CrossRef]
33. Capeluto, I.G.; Yezioro, A.; Shaviv, E. Climatic aspects in urban design—A case study. *Build. Environ.* **2003**, *38*, 827–835. [CrossRef]
34. Heusinger, J.; Sailor, D.J. Heat and Cold Roses of U.S. Cities: A New Tool for Optimizing Urban Climate. *Sustain. Cities Soc.* **2019**, *51*, 101777. [CrossRef]
35. Masuda, Y.; Ikeda, N.; Seno, T.; Takahashi, N.; Ojima, T. A Basic Study on Utilization of the Cooling Effect of Sea Breeze in Waterfront Areas along Tokyo Bay. *J. Asian Archit. Build. Eng.* **2018**, *4*, 483–487. [CrossRef]
36. Pallares-Barbera, M.; Gisbert, M.; Badia, A. Grid orientation and natural ventilation in Cerdà's 1860 urban plan for Barcelona. *Plan. Perspect.* **2021**, *36*, 719–739. [CrossRef]
37. Ng, E. Policies and technical guidelines for urban planning of high-density cities—Air ventilation assessment (AVA) of Hong Kong. *Build. Environ.* **2009**, *44*, 1478–1488. [CrossRef] [PubMed]
38. Capeluto, I.G. A methodology for the qualitative analysis of winds: Natural ventilation as a strategy for improving the thermal comfort in open spaces. *Build. Environ.* **2005**, *40*, 175–181. [CrossRef]
39. Da Silva, F.T.; Alvarez, C.E.d. An integrated approach for ventilation's assessment on outdoor thermal comfort. *Build. Environ.* **2015**, *87*, 59–71. [CrossRef]
40. Javanroodi, K.; Mahdavinejad, M.; Nik, V.M. Impacts of urban morphology on reducing cooling load and increasing ventilation potential in hot-arid climate. *Appl. Energy* **2018**, *231*, 714–746. [CrossRef]
41. Wei, X. Research on Reducing Carbon Consumption in Residential Community Spaces as Influenced by Microclimate Environments. *J. Urban Plan. Dev.* **2021**, *147*, 04021037. [CrossRef]
42. Shaeri, J.; Aflaki, A.; Yaghoubi, M.; Janalizadeh, H. Investigation of passive design strategies in a traditional urban neighborhood: A case study. *Urban Clim.* **2018**, *26*, 31–50. [CrossRef]
43. Abdou, N.; El Mghouchi, Y.; Hamdaoui, S.; El Asri, N.; Mouqallid, M. Multi-objective optimization of passive energy efficiency measures for net-zero energy building in Morocco. *Build. Environ.* **2021**, *204*, 108141. [CrossRef]
44. Sibilla, M. Developing a process-oriented approach towards Positive Energy Blocks: The wind-analysis contribution. *City Territ. Archit.* **2021**, *8*, 11. [CrossRef]
45. Ghiaus, C.; Allard, F.; Santamouris, M.; Georgakis, C.; Nicol, F. Urban environment influence on natural ventilation potential. *Build. Environ.* **2006**, *41*, 395–406. [CrossRef]
46. Song, J.; Huang, X.; Shi, D.; Lin, W.E.; Fan, S.; Linden, P.F. Natural ventilation in London: Towards energy-efficient and healthy buildings. *Build. Environ.* **2021**, *195*, 107722. [CrossRef]
47. Futcher, J.; Mills, G.; Emmanuel, R.; Korolija, I. Creating sustainable cities one building at a time: Towards an integrated urban design framework. *Cities* **2017**, *66*, 63–71. [CrossRef]
48. Lee, G.; Jeong, Y. Impact of Urban and Building Form and Microclimate on the Energy Consumption of Buildings—Based on Statistical Analysis. *J. Asian Archit. Build. Eng.* **2018**, *16*, 565–572. [CrossRef]
49. Tang, Y.; Sun, T.; Luo, Z.; Omidvar, H.; Theeuwes, N.; Xie, X.; Xiong, J.; Yao, R.; Grimmond, S. Urban meteorological forcing data for building energy simulations. *Build. Environ.* **2021**, *204*, 108088. [CrossRef]
50. Wilson, B. Urban form and residential electricity consumption: Evidence from Illinois, USA. *Landsc. Urban Plan.* **2013**, *115*, 62–71. [CrossRef]
51. Yang, J.; Wang, Y.; Xue, B.; Li, Y.; Xiao, X.; Xia, J.C.; He, B. Contribution of urban ventilation to the thermal environment and urban energy demand: Different climate background perspectives. *Sci. Total Environ.* **2021**, *795*, 148791. [CrossRef]
52. Li, C.; Wang, Z.; Li, B.; Peng, Z.-R.; Fu, Q. Investigating the relationship between air pollution variation and urban form. *Build. Environ.* **2019**, *147*, 559–568. [CrossRef]
53. Peng, Y.; Gao, Z.; Buccolieri, R.; Shen, J.; Ding, W. Urban ventilation of typical residential streets and impact of building form variation. *Sustain. Cities Soc.* **2021**, *67*, 102735. [CrossRef]
54. Hang, J.; Wang, Q.; Chen, X.; Sandberg, M.; Zhu, W.; Buccolieri, R.; Di Sabatino, S. City breathability in medium density urban-like geometries evaluated through the pollutant transport rate and the net escape velocity. *Build. Environ.* **2015**, *94*, 166–182. [CrossRef]
55. Wen, C.-Y.; Juan, Y.-H.; Yang, A.-S. Enhancement of city breathability with half open spaces in ideal urban street canyons. *Build. Environ.* **2017**, *112*, 322–336. [CrossRef]
56. Krüger, E.L.; Minella, F.O.; Rasia, F. Impact of urban geometry on outdoor thermal comfort and air quality from field measurements in Curitiba, Brazil. *Build. Environ.* **2011**, *46*, 621–634. [CrossRef]
57. Liu, Y.; Wu, J.; Yu, D. Disentangling the Complex Effects of Socioeconomic, Climatic, and Urban Form Factors on Air Pollution: A Case Study of China. *Sustainability* **2018**, *10*, 776. [CrossRef]
58. Liu, C.; Shu, Q.; Huang, S.; Guo, J. Modeling the Impacts of City-Scale "Ventilation Corridor" Plans on Human Exposure to Intra-Urban PM2.5 Concentrations. *Atmosphere* **2021**, *12*, 1269. [CrossRef]
59. Fang, Y.; Zhao, L. Assessing the environmental benefits of urban ventilation corridors: A case study in Hefei, China. *Build. Environ.* **2022**, *212*, 108810. [CrossRef]

60. Li, B.; Li, X.-B.; Li, C.; Zhu, Y.; Peng, Z.-R.; Wang, Z.; Lu, S.-J. Impacts of wind fields on the distribution patterns of traffic emitted particles in urban residential areas. *Transp. Res. Part D Transp. Environ.* **2019**, *68*, 122–136. [CrossRef]
61. Yang, J.; Shi, B.; Shi, Y.; Marvin, S.; Zheng, Y.; Xia, G. Air pollution dispersal in high density urban areas: Research on the triadic relation of wind, air pollution, and urban form. *Sustain. Cities Soc.* **2020**, *54*, 101941. [CrossRef]
62. Bahaj, A.S.; Myers, L.; James, P.A.B. Urban energy generation: Influence of micro-wind turbine output on electricity consumption in buildings. *Energy Build.* **2007**, *39*, 154–165. [CrossRef]
63. Mithraratne, N. Roof-top wind turbines for microgeneration in urban houses in New Zealand. *Energy Build.* **2009**, *41*, 1013–1018. [CrossRef]
64. Walters, R.; Walsh, P.R. Examining the financial performance of micro-generation wind projects and the subsidy effect of feed-in tariffs for urban locations in the United Kingdom. *Energy Policy* **2011**, *39*, 5167–5181. [CrossRef]
65. Tasneem, Z.; Al Noman, A.; Das, S.K.; Saha, D.K.; Islam, M.R.; Ali, M.F.; R Badal, M.F.; Ahamed, M.H.; Moyeen, S.I.; Alam, F. An analytical review on the evaluation of wind resource and wind turbine for urban application: Prospect and challenges. *Dev. Built Environ.* **2020**, *4*, 100033. [CrossRef]
66. Sharpe, T. Building mounted wind turbines on existing multi-storey housing. *Open House Int.* **2008**, *33*, 60–69. [CrossRef]
67. Kumar, R.; Raahemifar, K.; Fung, A.S. A critical review of vertical axis wind turbines for urban applications. *Renew. Sustain. Energy Rev.* **2018**, *89*, 281–291. [CrossRef]
68. Adam, K.; Hoolohan, V.; Gooding, J.; Knowland, T.; Bale, C.S.E.; Tomlin, A.S. Methodologies for city-scale assessment of renewable energy generation potential to inform strategic energy infrastructure investment. *Cities* **2016**, *54*, 45–56. [CrossRef]
69. Wang, B.; Cot, L.D.; Adolphe, L.; Geoffroy, S.; Sun, S. Cross indicator analysis between wind energy potential and urban morphology. *Renew. Energy* **2017**, *113*, 989–1006. [CrossRef]
70. Anup, K.C.; Whale, J.; Urmee, T. Urban wind conditions and small wind turbines in the built environment: A review. *Renew. Energy* **2019**, *131*, 268–283. [CrossRef]
71. Drew, D.R.; Barlow, J.F.; Cockerill, T.T. Estimating the potential yield of small wind turbines in urban areas: A case study for Greater London, UK. *J. Wind Eng. Ind. Aerodyn.* **2013**, *115*, 104–111. [CrossRef]
72. Millward-Hopkins, J.T.; Tomlin, A.S.; Ma, L.; Ingham, D.B.; Pourkashanian, M. Assessing the potential of urban wind energy in a major UK city using an analytical model. *Renew. Energy* **2013**, *60*, 701–710. [CrossRef]
73. Juan, Y.H.; Wen, C.Y.; Chen, W.Y.; Yang, A.S. Numerical assessments of wind power potential and installation arrangements in realistic highly urbanized areas. *Renew. Sustain. Energy Rev.* **2021**, *135*, 110165. [CrossRef]
74. Elbakheit, A.R. A Framework Towards Enhanced Sustainable Systems Integration into Tall Buildings Design. *Int. J. Archit. Res. ArchNet-IJAR* **2018**, *12*, 251–265. [CrossRef]
75. Juan, Y.-H.; Wen, C.-Y.; Li, Z.; Yang, A.-S. Impacts of urban morphology on improving urban wind energy potential for generic high-rise building arrays. *Appl. Energy* **2021**, *299*, 117304. [CrossRef]
76. Shiraz, M.Z.; Dilimulati, A.; Paraschivoiu, M. Wind power potential assessment of roof mounted wind turbines in cities. *Sustain. Cities Soc.* **2020**, *53*, 101905. [CrossRef]
77. Mancò, G.; Guelpa, E.; Colangelo, A.; Virtuani, A.; Morbiato, T.; Verda, V. Innovative Renewable Technology Integration for Nearly Zero-Energy Buildings within the Re-COGNITION Project. *Sustainability* **2021**, *13*, 1938. [CrossRef]
78. Van Timmeren, A.; Zwetsloot, J.; Brezet, H.; Silvester, S. Sustainable Urban Regeneration Based on Energy Balance. *Sustainability* **2012**, *4*, 1488–1509. [CrossRef]
79. Hachem-Vermette, C.; Singh, K. Analysis of Urban Energy Resources to Achieve Net-Zero Energy Neighborhoods. *Front. Sustain. Cities* **2021**, *3*, 663256. [CrossRef]
80. Mohammadnezami, M.; Ehyaei, M.; Rosen, M.; Ahmadi, M. Meeting the Electrical Energy Needs of a Residential Building with a Wind-Photovoltaic Hybrid System. *Sustainability* **2015**, *7*, 2554–2569. [CrossRef]
81. Wilke, A.; Shen, Z.; Ritter, M. How Much Can Small-Scale Wind Energy Production Contribute to Energy Supply in Cities? A Case Study of Berlin. *Energies* **2021**, *14*, 5523. [CrossRef]
82. Lee, J.; Park, J.; Jung, H.-J.; Park, J. Renewable Energy Potential by the Application of a Building Integrated Photovoltaic and Wind Turbine System in Global Urban Areas. *Energies* **2017**, *10*, 2158. [CrossRef]
83. Chong, W.T.; Naghavi, M.S.; Poh, S.C.; Mahlia, T.M.I.; Pan, K.C. Techno-economic analysis of a wind–solar hybrid renewable energy system with rainwater collection feature for urban high-rise application. *Appl. Energy* **2011**, *88*, 4067–4077. [CrossRef]
84. Koller, M.; Eckert, K.; Ferber, U.; Gräbe, G.; Verbücheln, M.; Wendler, K. Resource Management as Part of Sustainable Urban District Development. *Sustainability* **2022**, *14*, 4224. [CrossRef]
85. Micallef, D.; van Bussel, G. A Review of Urban Wind Energy Research: Aerodynamics and Other Challenges. *Energies* **2018**, *11*, 2204. [CrossRef]
86. Cooney, C.; Byrne, R.; Lyons, W.; O'Rourke, F. Performance characterisation of a commercial-scale wind turbine operating in an urban environment, using real data. *Energy Sustain. Dev.* **2017**, *36*, 44–54. [CrossRef]
87. Rodriguez-Hernandez, O.; Martinez, M.; Lopez-Villalobos, C.; Garcia, H.; Campos-Amezcua, R. Techno-Economic Feasibility Study of Small Wind Turbines in the Valley of Mexico Metropolitan Area. *Energies* **2019**, *12*, 890. [CrossRef]
88. Emejeamara, F.C.; Tomlin, A.S.; Millward-Hopkins, J.T. Urban wind: Characterisation of useful gust and energy capture. *Renew. Energy* **2015**, *81*, 162–172. [CrossRef]

89. Abohela, I.; Hamza, N.; Dudek, S. Effect of roof shape, wind direction, building height and urban configuration on the energy yield and positioning of roof mounted wind turbines. *Renew. Energy* **2013**, *50*, 1106–1118. [CrossRef]
90. Higgins, S.; Stathopoulos, T. Application of artificial intelligence to urban wind energy. *Build. Environ.* **2021**, *197*, 107848. [CrossRef]
91. Kaseb, Z.; Hafezi, M.; Tahbaz, M.; Delfani, S. A framework for pedestrian-level wind conditions improvement in urban areas: CFD simulation and optimization. *Build. Environ.* **2020**, *184*, 107191. [CrossRef]
92. Wang, B.; Geoffroy, S.; Bonhomme, M. Urban form study for wind potential development. *Environ. Plan. B Urban Anal. City Sci.* **2022**, *49*, 76–91. [CrossRef]
93. Grunwald, L.; Schneider, A.-K.; Schröder, B.; Weber, S. Predicting urban cold-air paths using boosted regression trees. *Landsc. Urban Plan.* **2020**, *201*, 103843. [CrossRef]
94. Ng, E.; Yuan, C.; Chen, L.; Ren, C.; Fung, J.C.H. Improving the wind environment in high-density cities by understanding urban morphology and surface roughness: A study in Hong Kong. *Landsc. Urban Plan.* **2011**, *101*, 59–74. [CrossRef]
95. Son, J.-M.; Eum, J.-H.; Kim, S. Wind corridor planning and management strategies using cold air characteristics: The application in Korean cities. *Sustain. Cities Soc.* **2022**, *77*, 103512. [CrossRef]
96. He, B.-J.; Ding, L.; Prasad, D. Urban ventilation and its potential for local warming mitigation: A field experiment in an open low-rise gridiron precinct. *Sustain. Cities Soc.* **2020**, *55*, 102028. [CrossRef]
97. Li, J.; You, W.; Ding, W. Exploring urban space quantitative indicators associated with outdoor ventilation potential. *Sustain. Cities Soc.* **2022**, *79*, 103696. [CrossRef]
98. An, K.; Wong, S.-M.; Fung, J.C.-H. Exploration of sustainable building morphologies for effective passive pollutant dispersion within compact urban environments. *Build. Environ.* **2019**, *148*, 508–523. [CrossRef]
99. Hang, J.; Luo, Z.; Sandberg, M.; Gong, J. Natural ventilation assessment in typical open and semi-open urban environments under various wind directions. *Build. Environ.* **2013**, *70*, 318–333. [CrossRef]
100. Yuan, C.; Ng, E. Building porosity for better urban ventilation in high-density cities—A computational parametric study. *Build. Environ.* **2012**, *50*, 176–189. [CrossRef] [PubMed]
101. Zheng, X.; Montazeri, H.; Blocken, B. Impact of building façade geometrical details on pollutant dispersion in street canyons. *Build. Environ.* **2022**, *212*, 108746. [CrossRef]
102. Lee, K.Y.; Mak, C.M. Effects of wind direction and building array arrangement on airflow and contaminant distributions in the central space of buildings. *Build. Environ.* **2021**, *205*, 108234. [CrossRef]
103. Ruiz, C.; Kalkman, I.; Blocken, B. Aerodynamic design optimization of ducted openings through high-rise buildings for wind energy harvesting. *Build. Environ.* **2021**, *202*, 108028. [CrossRef]
104. Hsieh, C.-M.; Jan, F.-C.; Zhang, L. A simplified assessment of how tree allocation, wind environment, and shading affect human comfort. *Urban For. Urban Green.* **2016**, *18*, 126–137. [CrossRef]
105. He, Y.; Tablada, A.; Wong, N.H. Effects of non-uniform and orthogonal breezeway networks on pedestrian ventilation in Singapore's high-density urban environments. *Urban Clim.* **2018**, *24*, 460–484. [CrossRef]
106. He, B.-J.; Ding, L.; Prasad, D. Outdoor thermal environment of an open space under sea breeze: A mobile experience in a coastal city of Sydney, Australia. *Urban Clim.* **2020**, *31*, 100567. [CrossRef]
107. Peng, L.; Liu, J.-P.; Wang, Y.; Chan, P.-w.; Lee, T.-c.; Peng, F.; Wong, M.-s.; Li, Y. Wind weakening in a dense high-rise city due to over nearly five decades of urbanization. *Build. Environ.* **2018**, *138*, 207–220. [CrossRef]
108. Maing, M. Superblock transformation in Seoul Megacity: Effects of block densification on urban ventilation patterns. *Landsc. Urban Plan.* **2022**, *222*, 104401. [CrossRef]
109. Lan, H.; Lau, K.K.-L.; Shi, Y.; Ren, C. Improved urban heat island mitigation using bioclimatic redevelopment along an urban waterfront at Victoria Dockside, Hong Kong. *Sustain. Cities Soc.* **2021**, *74*, 103172. [CrossRef]
110. Hsieh, C.-M.; Huang, H.-C. Mitigating urban heat islands: A method to identify potential wind corridor for cooling and ventilation. *Comput. Environ. Urban Syst.* **2016**, *57*, 130–143. [CrossRef]
111. Yuan, C.; Norford, L.; Ng, E. A semi-empirical model for the effect of trees on the urban wind environment. *Landsc. Urban Plan.* **2017**, *168*, 84–93. [CrossRef]
112. Zhan, Q.; Fan, Y.; Xiao, Y.; Ouyang, W.; Lan, Y.; Jin, Z.; Yin, J.; Zhang, L. Sustainable Strategy: Comprehensive Computational Approach for Wind Path Planning in Dense Urban Area. *Int. Rev. Spat. Plan. Sustain. Dev.* **2018**, *6*, 148–164. [CrossRef]
113. Liao, C.-M.; Huang, S.-J.; Yu, H. Size-dependent particulate matter indoor/outdoor relationships for a wind-induced naturally ventilated airspace. *Build. Environ.* **2004**, *39*, 411–420. [CrossRef]
114. Dai, S.F.; Liu, H.J.; Chu, Y.J.; Lam, H.F.; Peng, H.Y. Impact of corner modification on wind characteristics and wind energy potential over flat roofs of tall buildings. *Energy* **2022**, *241*, 122920. [CrossRef]
115. He, Y.; Tablada, A.; Wong, N.H. A parametric study of angular road patterns on pedestrian ventilation in high-density urban areas. *Build. Environ.* **2019**, *151*, 251–267. [CrossRef]
116. He, B.-J.; Ding, L.; Prasad, D. Enhancing urban ventilation performance through the development of precinct ventilation zones: A case study based on the Greater Sydney, Australia. *Sustain. Cities Soc.* **2019**, *47*, 101472. [CrossRef]
117. Bourne, M.; Arjomandi, M.; Kurji, R. The economic assessment of micro wind turbines for South Australia. *Energy Syst.* **2013**, *4*, 355–377. [CrossRef]

118. Culotta, S.; Franzitta, V.; Milone, D.; Moncada Lo Giudice, G. Small Wind Technology Diffusion in Suburban Areas of Sicily. *Sustainability* **2015**, *7*, 12693–12708. [CrossRef]
119. Evans, B.; Parks, J.; Theobald, K. Urban wind power and the private sector: Community benefits, social acceptance and public engagement. *J. Environ. Plan. Manag.* **2011**, *54*, 227–244. [CrossRef]
120. Scott, A.; Shannon, P.; Hardman, M.; Miller, D. Evaluating the cumulative impact problem in spatial planning: A case study of wind turbines in Aberdeenshire, UK. *Town Plan. Rev.* **2014**, *85*, 457–488. [CrossRef]
121. Broughel, A.; Hampl, N. Community financing of renewable energy projects in Austria and Switzerland: Profiles of potential investors. *Energy Policy* **2018**, *123*, 722–736. [CrossRef]
122. Peel, D.; Lloyd, M.G. Positive Planning for Wind-Turbines in an Urban Context. *Local Environ.* **2007**, *12*, 343–354. [CrossRef]
123. Teschner, N.A.; Alterman, R. Preparing the ground: Regulatory challenges in siting small-scale wind turbines in urban areas. *Renew. Sustain. Energy Rev.* **2018**, *81*, 1660–1668. [CrossRef]
124. Yuan, C.; Ng, E. Practical application of CFD on environmentally sensitive architectural design at high density cities: A case study in Hong Kong. *Urban Clim.* **2014**, *8*, 57–77. [CrossRef]
125. Anderson, W.P.; Kanaroglou, P.S.; Miller, E.J. Urban form, energy and the environment: A review of issues, evidence and policy. *Urban Stud.* **1996**, *33*, 7–35. [CrossRef]
126. Roseland, M. Dimensions of the eco-city. *Cities* **1997**, *14*, 197–202. [CrossRef]
127. Yigitcanlar, T.; Degirmenci, K.; Butler, L.; Desouza, K.C. What are the key factors affecting smart city transformation readiness? Evidence from Australian cities. *Cities* **2022**, *120*, 103434. [CrossRef]
128. Seto, K.C.; Churkina, G.; Hsu, A.; Keller, M.; Newman, P.W.; Qin, B.; Ramaswami, A. From low-to net-zero carbon cities: The next global agenda. *Annu. Rev. Environ. Resour.* **2021**, *46*, 377–415. [CrossRef]
129. Wang, J.; Zong, Y.; You, S.; Træholt, C. A review of Danish integrated multi-energy system flexibility options for high wind power penetration. *Clean Energy* **2017**, *1*, 23–35. [CrossRef]
130. Zheng, W.; Hou, Y.; Li, Z. A dynamic equivalent model for district heating networks: Formulation, existence and application in distributed electricity-heat operation. *IEEE Trans. Smart Grid* **2021**, *12*, 2685–2695. [CrossRef]
131. Carter, J.G.; Cavan, G.; Connelly, A.; Guy, S.; Handley, J.; Kazmierczak, A. Climate change and the city: Building capacity for urban adaptation. *Prog. Plan.* **2015**, *95*, 1–66. [CrossRef]
132. Amaral, A.R.; Rodrigues, E.; Gaspar, A.R.; Gomes, Á. Review on performance aspects of nearly zero-energy districts. *Sustain. Cities Soc.* **2018**, *43*, 406–420. [CrossRef]
133. Webb, B. The use of urban climatology in local climate change strategies: A comparative perspective. *Int. Plan. Stud.* **2017**, *22*, 68–84. [CrossRef]
134. Hebbert, M.; Mackillop, F. Urban climatology applied to urban planning: A postwar knowledge circulation failure. *Int. J. Urban Reg. Res.* **2013**, *37*, 1542–1558. [CrossRef]
135. Arbolino, R.; Carlucci, F.; De Simone, L.; Ioppolo, G.; Yigitcanlar, T. The policy diffusion of environmental performance in the European countries. *Ecol. Indic.* **2018**, *89*, 130–138. [CrossRef]