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Effects of built environment morphology on wind turbine noise exposure at building façades

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ABSTRACT

With wind farms installed in urban and suburban areas, the noise exposure of buildings is affected both by distance attenuation and the morphology of the built environment. With the aim of exploring the noise-resisting effects of built environment morphology, three kinds of typical suburban areas in the UK were sampled and noise maps were generated based upon an idealised modern wind turbine placed at various setback distances from each site. Relationships between morphological indices and building façade exposures were examined through regression analyses. Noise reduction levels of five morphological indices were given in terms of resisting wind turbine noise with different source-receiver (S-R) distances, and at different frequencies. The results show that built environment morphology has considerable effects on resisting the noise exposure of buildings and can create a quiet façade with up to 13 dBA difference to the most exposure façade. Among the five indices, building orientation is found to be most effective in resisting the noise exposure of building façades, followed by the length and shape of the building. The noise resistance effects vary by different S-R distances and differ by frequency. Four morphological indices are found to be effective in resisting noise at low frequencies, typically at 50 Hz.

1. Introduction

Wind turbines are playing an increasing role in the global process of producing renewable energy. As onshore wind farms are becoming a common feature of landscapes in many countries, there is an increasing likelihood that proposed projects would be closer to sensitive landscapes and residential areas than ever before [1]. Nowadays there is a development towards integrating large-scale wind turbines within urban environment, especially in elevated or coastal locations [2]. In the UK, a number of large-scale wind turbines have been introduced into suburban and urban settings, some of these as close as 350 m from densely populated residential areas, such as the wind turbines in the suburbs of Bristol, Dundee, and Nottingham. Although wind speeds are relatively lower in built-up areas than in remote rural areas [3,4], large-scale urban wind energy can be successfully implemented, as proposed by recent studies [2,5]. Since the properties of urban and residential areas with uniformed buildings and turbulent air are unsuitable for small turbines [6], large wind turbines that are installed higher can take advantage of optimum wind conditions [7,8]. More importantly, there are good reasons for developing wind turbines in an urban and suburban environment where electricity is consumed since it can reduce electricity loss in long-distance transmission [9] and can reduce network costs due to its proximity to population of high demand [10]. It is also documented that urban siting of wind turbines gains more support of the local community, unlike rural wind farms that are often opposed by residents on aesthetic rural grounds [11]. These advantages herald considerable potential of future wind energy projects to be fully developed in urban environments.

However, the urban environment has unique challenges in exploitation of large wind turbines: One of the main obstacles is the noise pollution to the surrounding residential areas. Noise from wind turbines in residential areas is dominated by aerodynamic sounds with large components at low-frequencies (below 200 Hz) produced during the downward movement of the blade [12], which is less attenuated by buildings than mid- to high-frequency sound [13]. The potential adverse impacts of wind turbine noise on neighbouring residents has been attracting considerable interest. Large field studies have been conducted focusing on the noise impact of rural and suburban wind turbines, with dose-response relationships being elucidated

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Nomenclature

SPL	Sound Pressure Level [dB]
Source-receiver distance ($D_{S\text{-}R}$)	Distance between the wind turbine and the receiver building [m]
Length (L)	The length of the longer façade of the building [m]
Shaped layout	Building with an L/U/H shaped, in-rectangular floor plan
Compactness index ($D_{S\text{-}R}/D_1$)	Ratio between source-receiver distance ($D_{S\text{-}R}$) and the distance from the nearest building at the front along the incidence wave (D_1)
Orientation (A)	The angle between the incidence wave and the longer façade [degree]

between noise levels and annoyance [14–16]. Exposure to noise pollution may further cause environmental health concerns, and health risks such as dizziness, headache, feeling tense and irritable [17,18]. It is possible that locating wind energy in highly populated urban and suburban areas may exacerbate the noise impact. However, to date there is little research towards noise impact of large-scale wind turbines in urban environments with large coverage of residential buildings. In addition, a previous study has already indicated that in built-up areas, the sound levels at dwellings is probably overestimated using the existing calculation methods for flat, rural landscapes [19]. Therefore, there is a need to investigate the distribution of wind turbine noise in densely built residential areas with a focus on localised noise exposure on and around receptors' building façades, with the purpose of identifying the effects of built environment morphology on the noise exposure from urban turbines.

The morphology of the built environment has a large effect on the exploitation of urban wind energy. Despite the fact that several works have been done on the effect of built environment morphology on urban wind profile and energy yielding [4,20,21], no or very little work has been done on its effect on wind turbine noise resisting. It has been found that the resisting effects of built environment morphology of the residential areas create large variances among wind turbine noise exposures at different buildings [22]. This is due to the fact that noise propagation in a densely built residential area is affected by the acoustical effect of absorbing, reflecting, and shielding from buildings [23], which promotes the creation of protected areas or shadow areas in an urban context [24]. Morphological parameters – such as the height, shape, and orientation of the building, as well as the spacing between adjacent buildings – largely influence the above effects and hence may contribute to obtain reduced levels of noise pollution from wind turbines [25]. Some works have already demonstrated the effects of morphology in urban or residential areas on the distribution of traffic, bird, and aircraft sounds using noise mapping techniques. Most of the studies have put emphasis on meso-scale urban morphology such as road and building coverage ratio, building plan area fraction, building frontal area index, and have related these parameters to the average, maximum and minimum noise exposure within the studied urban grid [26–30]. Other studies focus on the noise resisting effects of urban layout and formation such as urban density, green space ratio, road length and intersections, at larger urban-scale [31,32]. For this reason, the results of previous studies cannot be directly applied in predicting wind turbine noise with a focus on localised noise exposure at receptors at the building-scale, i.e. the noise exposure on and around the façades of a receptor's dwelling. Given the fact that little work has assessed the possible effects of built environment morphology on wind turbine noise, there is a need to model and graphically show the distribution of wind turbine noise in typical residential layouts, and to examine how these sound levels might be resisted by different types of built environment morphologies, such as the shape of the building, and the spacing between adjacent structures.

The morphology at building scale is also important. In previous studies on the impact of wind turbine noise in residential areas, noise levels that the residents were exposed to were normally calculated in terms of A-weighted sound pressure levels (SPLs) outside their dwelling, based on outdoor sound propagation formula [14,15], which mainly present the noise at the most exposed place but consider less the variance among all the façades of the building. Since buildings are three-dimensional objects, identifying the noise exposures at multiple sides can play an equally important role in determining indoor noise pollution at various rooms [33] hence influencing noise perceptions at home. In particular, it is indeed important to examine the presence of a quiet façade, which has been proved to have positive effects on noise perception in a number of studies [34–36]. A study on road traffic noise has demonstrated that a large difference in exposure (10–20 dB) between the most and least exposed side of a dwelling is associated with significantly lower noise annoyance and less prevalence of noise-induced health problems [34]. The recent studies have found that the actual exposure level at the least exposed façade itself has a direct effect on annoyance, independent of that at the most exposed façade, by showing that higher exposures at the least exposed façade may increase adverse noise impacts [35,36]. The EU Environmental Noise Directive [37] has put emphasis on the benefit of quiet façade and states that major EU cities should indicate how many persons live in dwellings with a quiet façade and protect quiet areas by means of noise action plans. However, an accurate method for calculating wind turbine noise levels at the quiet façade has found little presence in the literature particularly with reference to building and site parameters that influence the distribution of wind turbine noise at the quiet facades. Pilot studies have modelled the distribution of wind turbine noise around all façades of a dwelling using noise mapping techniques that take into account parameters of buildings and the ground surface on generic residential areas [22,38]. As found in pilot studies, the levels of wind turbine noise at the least exposed façade [22] and around all façades on average [38] are both highly related to built environment morphology, which also depend on the setback distance to the wind turbine. In a certain setback condition, a better designed residential area can resist wind turbine noise and substantially reduce the noise level at the quiet façade. The noise resisting effect of built environment morphology merits further investigation.

The aim of this research is therefore to explore the noise-resistance of built environment morphology of densely built residential layouts, in terms of creating shielded areas and quiet façades with relatively less noise exposure from urban or suburban wind turbines. More specifically, by defining five morphological indices, this paper demonstrates how the changing of a morphological index may reduce the noise level at the least exposed façade and at all façades on average. This paper, based on noise mapping techniques, examines the sound level distribution of wind turbine noise at dwelling façades in generic residential areas, with more focus on the quiet façade that needs to be well protected. The relative importance of various morphological indices is examined on different levels of wind turbine proximity and at different sound frequencies.