Installation of a Small Building-Mounted Wind Turbine: A Case Study from Idea to Implementation

Quentin Deltenre and Mark C. Runacres

Abstract In Belgium, the installation of a small wind turbine on rooftops is still very uncommon. Currently, there is no dedicated legal framework governing the installation on a building. Nevertheless, over the past years, our research group has received several demands from building owners wanting to install one or several turbines on their rooftop. The lack of a dedicated framework requires increased attention throughout the whole procedure. To prevent potentially harmful installations, we developed an approach to assess the feasibility of such initiatives. This paper reports a complete feasibility study to install a 3 kW wind turbine on the South Tower (the highest building in Belgium). The paper reviews the main steps from the concept towards the installation of a turbine on a high-rise rooftop. In overall terms, the installation of a 3 kW turbine on top of the South Tower has little impact on the building and its nearby environment. From an environmental perspective, the installation of a small building-mounted wind turbine on a rooftop can be meaningful. However, even in good wind conditions, the economic viability of the 3 kW turbine is low. This is mainly caused by the high study cost. Therefore, their global cost might still hold back potential investors.

1 Introduction

In Europe, decentralised energy production has become an increasing trend [1]. This is partly explained because Europe has set a goal to produce 20% of renewable energy by 2020 [1]. This growth is also observed for small wind turbines where the market has experienced a rise of 5 and 8% in 2014 and 2015 respectively [2, 3]. Although less pronounced, the average cost of a small turbine has declined with an annual average decrease of 2.7% [3]. While one observes an increasing demand and

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a decreasing cost, it must be emphasised that the market is still very immature and the quality standard of several turbines is very poor [4].

In cities, wind energy production is rather marginal because of insufficient space. However, rooftops in cities offer a good potential for energy production. Generally, photovoltaic panels are installed to produce electricity. Yet, there is a growing interest to install small wind turbines on rooftops [5]. In fact, tall buildings often have a good wind resource thanks to their height and reduced shadowing by their immediate surroundings [6].

While research is often optimistic about the installation of small building-mounted wind turbines (SBMWT), no experimental projects have been found to be viable. Two fairly recent reports have gathered results of approximately 30 SBMWT projects after a few years of installation [7, 8]. The primary objectives of these projects were threefold: raise awareness about renewable energy production, increase the building visibility and have a viable project. While the two first goals were often met, none of these projects have demonstrated good profitability. The reason why these projects failed comes mainly from a poor feasibility study, e.g., no proper micro-siting, wrong annual energy production (AEP) predictions and poor-quality turbines. Other famous turbine projects, that were originally promoted by the media, provide no public reports after several years of installation (e.g. Eiffel Tower (Paris) [9] and Strata Tower (London)).

However, the tallest rooftops of a city often have a good potential for wind energy production. We performed measurements in Brussels supporting this conclusion [10]. Having good contact with the building owner of the tallest high-rise in Belgium, we were able to do a full feasibility study and submit a building permit for the first pilot project on their roof.

With this project, we want to verify whether a building-mounted project is feasible and viable in Belgium. This paper describes every step of the feasibility study performed on the South Tower, including the steps towards the installation of the turbine. Based on the feasibility study, a methodology for further projects is proposed.

The article is divided as follows: Section 2 proposes a methodology based on the feasibility study and the encountered difficulties. Section 3 concludes the paper and discusses the perspectives for new projects.

2 Feasibility Study for the South Tower

Our research group conducted several studies in the Brussels Region showing that only tall buildings can achieve good wind conditions [10, 11]. To a certain extent, small wind turbines installed on these roofs show good return on investment. An economic analysis revealed that the dynamic payback period for turbines between 3 and 6 kW was between 7 and 10 years [10]. Aside from the profitability of the turbine, there are a number of other concerns that must be verified before the actual installation. In this section we discuss the different aspects of the feasibility study realised for the South Tower, a high-rise of 150 m high (Fig. 1).

Fig. 1 Picture taken at 400 m from the South Tower

The very first part of a feasibility study is to determine the wind conditions above a rooftop. Unfortunately, because of time constraints, we could not measure the wind conditions with a wind measurement mast on the South Tower. However, we did measure the wind conditions on other high-rises in Brussels, e.g. the Hotel (103 m). We intentionally write some of the measurement results of the Hotel in the introduction of this section because they are not part of the feasibility study realised for the South Tower. Further sections focus entirely on the South Tower.

After 13 months of measurement, the average annual wind speed on the Hotel was 5.8 m/s with a maximum at 21.9 m/s. The annual average turbulence intensity was 25.7%. A wind rose of the average turbulence intensity per orientation can be observed in Fig. 2.

The annual average turbulence intensity is higher than 18%, the value assumed for small wind turbines in IEC 61400-2. One should be aware that wind measurements on the Hotel have been realised at 9 m in height while the recirculation region in the centre of the roof is 12.3 m. This partly explains the high turbulence level. A recent article [12] studied the suitability of IEC 61400-2 and the normal turbulence model (NTM) for small wind turbines built in complex environment. They found out that the standard method is not applicable for these turbines (the model they developed result in loadings being generally higher than the ones calculated with the standard). Therefore, it is very important for the wind turbine developers to use caution while determining the design loads. For the South Tower pilot project, extra control/maintenance should be organised.

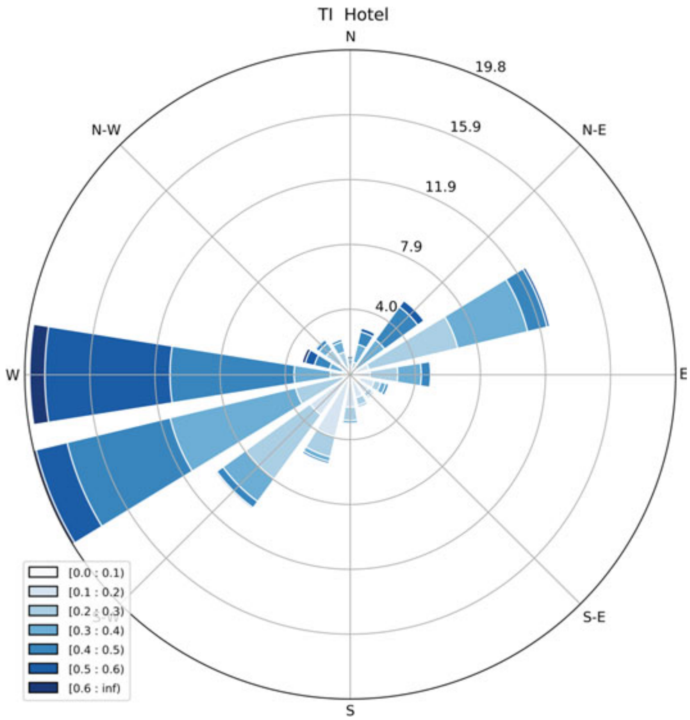


Fig. 2 Wind rose of the average turbulence intensity at 9 m high on the Hotel. The radial scale represents the number of data for each direction and the colour gradient represents the turbulence intensity of these data

2.1 Micro-siting

The wind conditions above a rooftop are strongly affected by its surroundings and by its massing, i.e. height and dimension. Without guidance, these conditions make it difficult to install a wind turbine in the most effective position. Therefore, proper micro-siting is essential to ensure an optimal energy production of the turbine [6].

Calculations were performed for the southwestern wind direction, which is the dominant wind direction in Brussels. CAD models were constructed of the building where the wind turbine would be installed, and of a number of surrounding buildings (Fig. 3).

The CAD model is then introduced in the CFD code OpenFOAM, to produce a three-dimensional wind map of the wind over the building. By producing the appropriate slices (horizontal above the building at a height above the roof that is appropriate for a wind turbine, and vertical along the length-axis of the building) the optimal locations for the installation of a rooftop-mounted wind turbine can be determined.

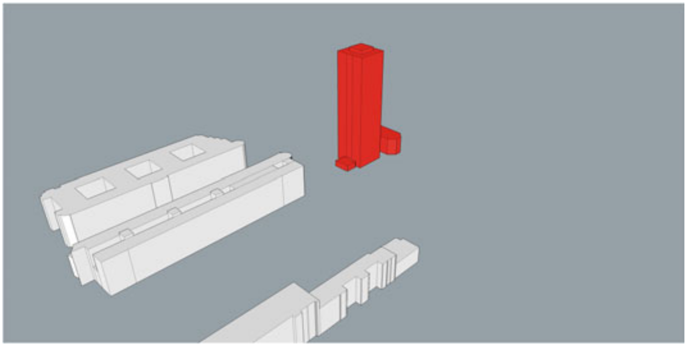


Fig. 3 3D model of the South Tower built with Google SketchUp. The South Tower is painted in red

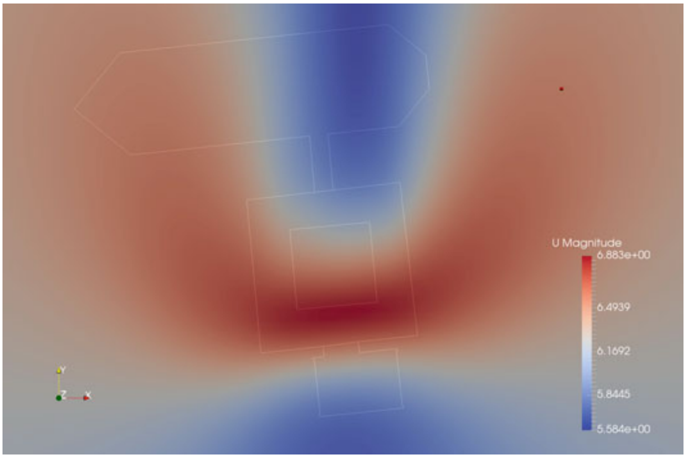


Fig. 4 Horizontal slice of the wind speed at 10 m above the roof of the South Tower. The outline of the underlying roof is shown in white

The wind pattern over the South Tower is very simple, and has a profile typical of a forward step. A detailed quantification of uncertainties, although useful, falls outside the scope of the present paper. A wind turbine is best placed on the upstream side of the upper part of the roof, on the left bottom corner of the square (Fig. 4). This location would ensure higher wind speeds. It is not necessary to use a mast higher than 10 m.

2.2 *Stability Assessment*

A stability office assessed the possibility to install a 5 kW turbine on the roof of the South Tower [13]. For safety reasons, but also because this is a pilot project, we preferred to limit the power of the turbine. The main goal is to design an anchoring system between the mast of the turbine and the roof of the building. The existing structure of the building will then be verified to check whether reinforcement is required. The stability assessment is performed with the Eurocodes [14–16]. The structural integrity of the mast and the rotor will not be assessed in this document because this was already done in the certification process of the turbine (IEC 61400).

In Europe, Eurocodes are a set of norms that are used for the design and sizing of buildings and structures. Specific structures (e.g. masts, chimneys, steel bridges) have their own standard that specifies the steps to be properly dimensioned. Small building-mounted wind turbines, being rather marginal, have no dedicated Eurocode that gives all these steps. Therefore a combination of different norms was used to make the assessment.

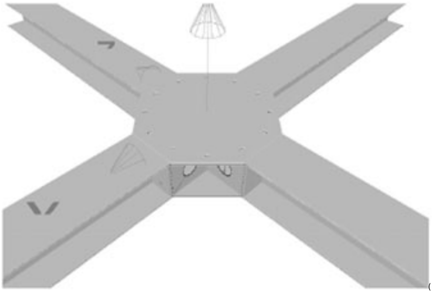
There are three main steps in this assessment: wind forces acting on the turbine, static verification and dynamic verification. These steps are explained in the next paragraphs.

1-Wind Forces Acting on the Turbine
The goal of this first part is to determine all forces acting on the wind turbine. These forces will be used in the two other paragraphs. With the Eurocodes, it is possible to calculate the wind loading on the mast, the rotor and also measure the maximal internal forces inside the new structure (the anchoring system).

2-Static Verification
The static verification aims to size the structure under extreme wind conditions. Based on the loadings assessed in the first part, an anchoring system between the mast of the turbine and the rooftop was developed. The system is an 'X' bracing composed of two HEA300 steel beams (Fig. 5, left). The mast of the turbine is positioned in the center of the 'X'. Then, it is verified that the steel beams will not buckle and that they can support fatigue (welded connections).

When the anchoring setup is chosen, the next step is to decide how to connect the setup to the roof. To avoid water infiltration by drilling the roofing membrane, counter-weights (1.11 m^3 on each foot) were designed to fix the structure to the roof. Finally, existing concrete beams and columns of the building are verified for these new loadings. Only the beams request a reinforcement, realised with steel elements.

3-Dynamic Verification
This last part focuses on the calculation of maximal accelerations caused by the turbine. By means of finite element modelings (Fig. 5, right) the eigenmodes of the structure can be calculated. With these modes, it is possible to calculate the maximal accelerations and displacements (horizontal and vertical) in the building. Comparing these results with the comfort criteria of the standard [17], it is safe to predict that these accelerations and displacements are too small to be perceived by the user. It means that nobody working in the building will suffer from vibrations caused by the turbine installation.



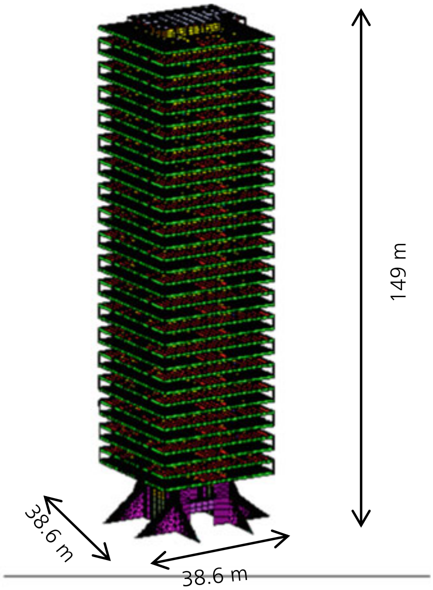


Fig. 5 Anchoring system that is proposed to fix the mast of the turbine to the rooftop (left). Finite element model that is used to determine the accelerations and displacements caused by the wind turbine (right)

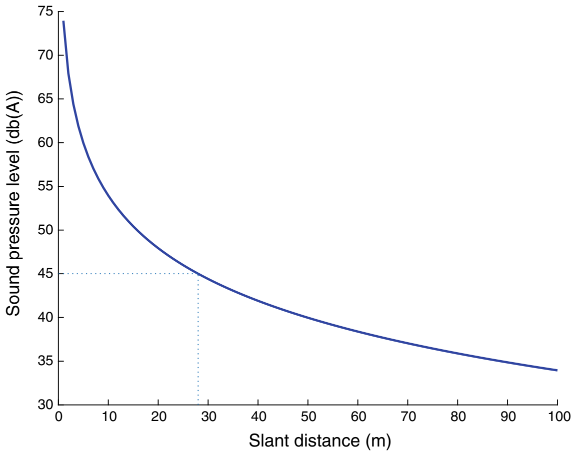


Fig. 6 Sound pressure level as a function of the slant distance from the hub height of the turbine. This graph is derived from the relation between the sound power and the sound pressure level, using the sound level from the certification. One can observe that the noise level is below 45 dB(A) at 30 m from the hub height (noise reflection and absorption is not considered). This 45 dB(A) noise level is acceptable for offices

2.3 *Environmental Concerns*

Wind turbines often raise several relevant concerns on their nearby environment, i.e., noise, shadow, visual impact, biodiversity and air transport. These concerns are addressed in the following paragraphs, for the South Tower (Fig. 6).

2.3.1 Noise

We performed several on-site noise measurements for a 5 kW turbine installed on a field test in Puyenbroeck. The results of that study are shown in Fig. 7. The figure indicates the minimum slant distance between the rotor axis and the ground at which someone must stand to have a sound level below a certain limit. For example, if one considers the red curve, it points out that for an average wind speed of 6 m/s, the noise at 57 m from the rotor is below 40 dB(A). This is a reassuring result because direct noise emissions from a SBMWT are low, especially compared to the average urban sound pressure level (50–70 dB(A)) [18].

For the South Tower, we studied theoretically the ambient noise before and after the installation of a turbine. This study was realised for a wind turbine of 10 kW (three times more powerful than the one that is foreseen on the roof) and for a wind speed of 8 m/s. Using the average wind speed at the location and a Raleigh distribution, the amount of time the wind speed exceeds 8 m/s is around 28.5%. A 5 kW turbine operating at that particular wind speed produces a noise equivalent to 45.1 dB(A) at 60 m slant distance from the hub (Fig. 7).

Finally, the certification of the turbine that will be installed on the roof also provides a noise level. This study indicates that the turbine produces 49 dB(A) at 25 m distance at a wind speed of 8 m/s [19]. Using the relation between sound pressure level and sound power, it is possible to plot the sound pressure level reduction as a function of the slant distance for that turbine (Fig. 6). One can observe that the noise

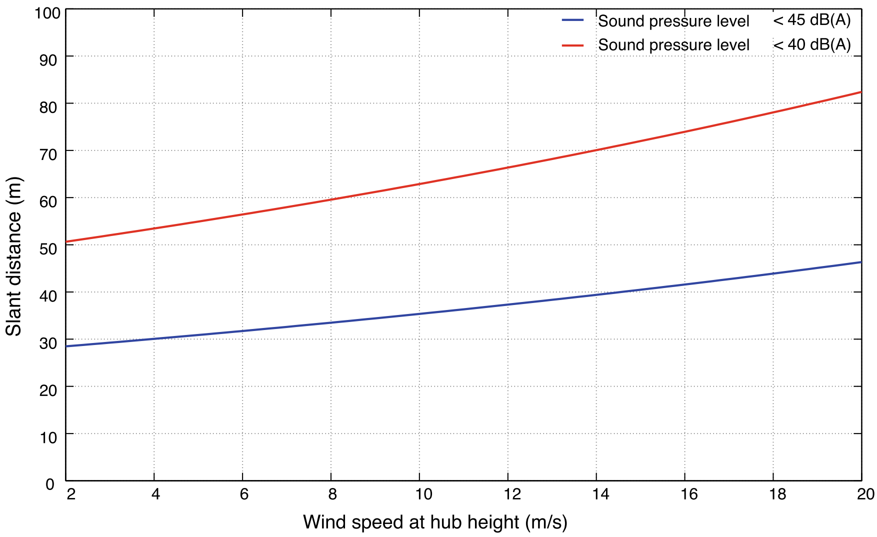


Fig. 7 Experimental results of the acoustic study performed on a 5 kW turbine. The red line (above) represents the 40 dB(A) limit, the blue line (below) indicates the 45 dB(A) limit. The graph gives the necessary minimal slant distance between a turbine and a point as a function of the wind speed. For a wind speed of 6 m/s, the minimal slant distance to reach a noise level below 40 dB(A) is 55 m

level is below 45 dB(A) at 28 m from the hub height (noise reflection and absorption are not considered). This noise level is acceptable for offices. The first office floor below the wind turbine is approximately at 30 m from the hub. Taking into account the noise absorption and reflection, one can expect lower noise level in reality.

These estimated noise values are small and will not be perceived by people walking in the streets around the building. Employees working at the last inhabited floor might perceive the noise during wind gust periods. Nevertheless a technical floor increase the distance between the last office floor and the roof, which reduces the noise hindrance. Moreover, the technical floor contains the machinery that operates the lifts in the building. These lifts produce vibrations and noise during their use, i.e., during daytime. It is safe to say that the turbine direct noise will be hardly noticeable above the noise produced by the lifts and the HVAC systems on the roof. The structure-borne sound caused by such a small turbine is also believed to be smaller than that of HVAC systems and lifts.

2.3.2 Shadow Flicker

The shadow cast by an operating wind turbine can sometimes be perceived by an observer as *flickering*. Because of the low solidity of the rotor (typically three blades), light from the sun is only periodically blocked, resulting in a flickering shadow. When such a shadow falls on windows of nearby residences or offices, a certain nuisance can be experienced. Therefore a proper shadow flicker study cannot be omitted when assessing the possible impact of the installation of a wind turbine.

To be able to encounter such an event, following conditions must be met simultaneously:

- The wind turbine must be in operating condition, i.e. the rotor must be spinning.
- It must be daytime with clear skies. Diffuse light that penetrates clouds is insufficient to generate distinct shadows.
- The observer should not be in the rotor plane.
- Only properties within 135 degrees on either side of north of the turbine can be affected at Belgian latitudes [20].

Within the framework of the regional planning of Flanders, a technical note was published describing guidelines that are to be considered when evaluating a potential site for the installation of a small wind turbine [21]. The guideline prescribes a minimum distance of two times the total height of the turbine, i.e., tip height including building height when mounted on a structure (top view is provided in Fig. 8).

Situation for the South Tower

The South Tower, with a height of 150 m, is a clear example of the guidelines being too conservative. In Fig. 9, a disk is drawn conform to the prescribed radius. The indicated area is clearly oversized. This claim is supported by the following 3 observations:

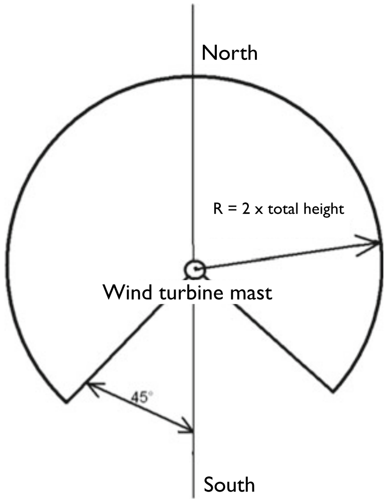


Fig. 8 Minimum required distance to avoid nuisance from shadow flicker

- We observed the tower shadowing from Google Maps. In Fig. 10, one can see the South Tower and its projected shadow on the close environment. The shadow of the mast (more than 10 m high and 1 m wide) is not identifiable. It is therefore reasonable to believe that the shadow of a small wind turbine would also not be distinguishable.
- Legislations limit the shadow flicker effect at 30 hours per year and 30 minutes per day [22]. To analyse the shadow throughout the year, a 3D model of the South Tower was built in Google SketchUp. The programme is able to assess the shadow of any object at any time of the year. The shadow will move very fast over the surrounding buildings, only affecting a single observer for a few minutes. Since in a few days the path of the sun will also already have changed, a single building will never be in the path of the shadow of the turbine for more than a few minutes a year.
- Several rules of thumb are used for quick shadow assessment [23]. The shadow flicker effect does not exceed a distance equals to 10 times the rotor diameter of the turbine. The 3 kW turbine having a diameter of 4.4 m, the shadow flicker would be limited to a sphere of 44 m. In the surroundings of the South Tower, the tallest buildings are 45 m high, which is still far from the shadow flicker boundary.

The South Tower was evaluated and no considerable risk for shadow flicker was found. It is worth noting that, in the case a residence is located within the prescribed safety radii, nuisance cannot be accurately determined until an assessment has been made of e.g. the windows widths, the uses of the rooms and the effect of intervening topography and other vegetation [22].

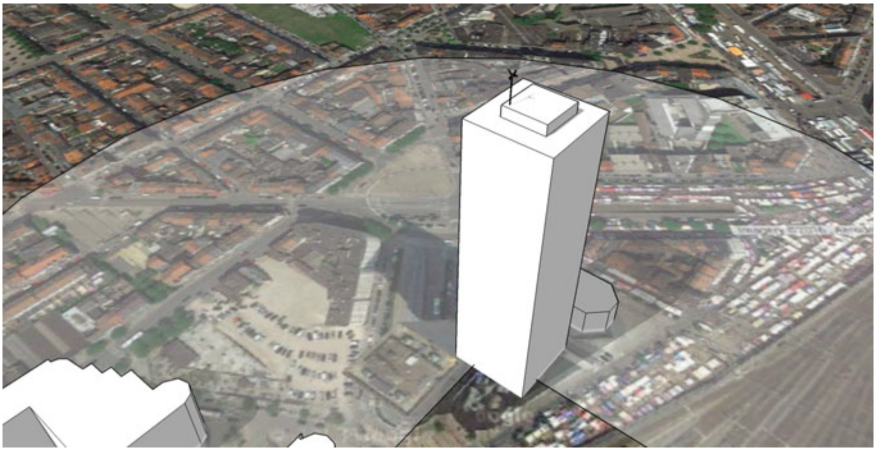


Fig. 9 Shadow flicker study performed in Google SketchUp. A 3D model of the building was designed. A small wind turbine was installed on a potential location. The shadow of the turbine in this Figure is taken the 2nd of July, at 1 PM. In summer, the shadow is completely projected on the rooftop surface

Fig. 10 Real shadow of the South Tower on its surroundings

2.3.3 Visual Impact

The visual impact of a wind turbine on the South Tower is expected to be small. Since the rooftop is already rather crowded with equipment (Fig. 1), the visual impact of the turbine should be minimal (Fig. 11).

Fig. 11 Mock-up of a wind turbine installed on the South Tower

2.3.4 Biodiversity

To quantify the impact of a SBMWT on the biodiversity (i.e. birds and bats), it is necessary to verify that the turbine is not installed close to sensitive zones (e.g. green spaces, migratory routes, natural reserves). Brussels offers a 'biodiversity map' where all these zones are highlighted [18]. The South Tower being far from these zones, we can expect a low impact on biodiversity [11].

A research has published a synthesis of Human-related Avian Mortality in Canada. This study indicates that birds killed by wind energy (in general) is less than 1 on 100,000 deaths [24]. These results support our expectations that the impact on biodiversity in the city will be small.

2.3.5 Air Traffic

The Belgian legislation proposes a memorandum that legislate beacons for obstacles [25]. This document requires that a notice must be sent for all installations that present a danger for aviation. Every object having a height larger than 150 m is considered as an obstacle and should be equipped with beacons. Nevertheless, if another obstacle on the same rooftop is higher than the new one (i.e. the turbine), it is not necessary to install such a device.

During the building permit procedure, the Brussels Region asked the advice of the Federal Public Service of Mobility. Because no beacons were already present on the South Tower, they required the installation of a beacon on one of the tallest obstacles of the roof. This beacon has nothing to do with the wind turbine per se, but was done to comply with the actual regulations from the Region.

2.4 Economic Viability

Research on economic viability of SBMWT has been limited. As stated above, a report listed the energy production results of 24 wind turbines in the UK [7]. Walters, R. et al. converted the energy production from these 24 turbines into revenues, in a net present value (NPV) framework [26]. This paper reveals that the investment for small wind turbines in an urban environment is unfavourable. More than 95% of the locations would score low NPVs. Another report, equivalent to the Warwick case studies, examined 6 building-mounted turbines installed in the USA [8]. This report provides the discounted payback period (DPP) (if available) for the 6 turbines. Results show that none of these turbines are profitable, all having a payback period larger than their lifetime.

Having a closer look at the profitability of small wind turbines, results are better but not ideal. A publication from the Internal Energy Agency on wind energy reveals a levelised cost of energy (LCOE) varying between 0.15 and 0.35 USD/kWh (i.e. 0.13–0.31 EUR/kWh) [27]. In 2016, another publication analysed 50 installed small wind turbines installed in the USA [28]. The LCOE varies a bit more: 0.05–0.45 USD/kWh (0.04–0.39 EUR/kWh). In Belgium, the cost of electricity neighbours 0.20 EUR/kWh [29], which is much lower than the higher limits from these two reports.

Based on these reports, one observes that building-mounted turbines are still rarely economically viable. Conclusions of these reports mention several reasons for this low return: wrong prediction of the energy production, wrong power curves from the manufacturers or numerous downtime periods.

In the framework of this feasibility study we assessed the LCOE and DPP of small wind turbines installed on the South Tower. The LCOE can be defined as the total life-cycle cost (TLCC) divided by the discounted energy production (TDEP). The total life-cycle cost can be expressed as

$$\text{TLCC} = \sum_{n=0}^{N} \frac{C_n}{(1+r)^n}, \tag{1}$$

where C_n is the cost in year n, N the lifetime of the turbine in years and r the discount factor. In this study, we assume that the only costs were the investment cost (I_O) and the operation-and-maintenance costs (C_{OM}). Then, the total discounted energy production can be expressed as

$$\text{TDEP} = \sum_{n=1}^{N} \frac{E_n}{(1+r)^n}, \tag{2}$$

where E_n is energy production in year n. If we assume that the OM costs and the energy production are constant every year, a represents the annuity factor and is defined by

$$a = \sum_{n=1}^{N} \frac{1}{(1+r)^n} = \frac{1-(1+r)^{-N}}{r}. \tag{3}$$

Using Eqs. (1), (2) and (3), the LCOE is calculated with

$$\text{LCOE} = \frac{I_0 + aC_{\text{OM}}}{aE}, \tag{4}$$

where E is the annual energy production of the turbine.

The DPP is the required time to recover the money invested in a project, taking the time value of money into account. This metric is of interest when risk is an issue (i.e. significant uncertainties in the project). It gives the investor a reliable duration for which his capital is at risk [30].

The discounted payback period is calculated based on the NPV

$$\text{NPV} = \sum_{n=1}^{N} \frac{CF_n}{(1+r)^n} - I_0, \tag{5}$$

where I_0 is the investment cost, CF_i is the cash flow in year n, r is the discount rate and N is the power plant's lifetime. The NPV sums all discounted cash flows over the lifetime of the project at a determined rate (i.e. the discount rate) and subtracts the investment cost. When the NPV of a project is positive, it indicates that the expected earnings are higher than the foreseen costs. Although the NPV is positive, it does not mean that the investment is cost effective. The analyst must be careful and compare the result with other potential investments.

These two factors have been studied for different wind speeds and wind turbines. Having no wind measurement data for the South Tower, we consider 3 average wind speeds that we can expect on such a building. According to wind measurements realised on other buildings (i.e. the Hotel, see Sect. 2), 4 m/s is very unlikely, 5 m/s is slightly underestimated and 6 m/s is a bit overestimated. The annual energy production of the turbines is taken from the turbines' certifications. The values of the parameters in Eqs. (4) and (5) can be found in Table 1. The South Tower being an office building, we took into account the related incentives. We also considered that all the energy produced would be consumed by the building, as stated by the owner. In the framework of this pilot project, we wanted to limit the impact of the installation by choosing a smaller wind turbine (3 kW). We also calculated these two economic factors for more powerful turbines (5 and 10 kW). Nevertheless, the impact of a

Table 1 Values of the parameters of the economic study

Parameters	Values
Investment cost	5,500 EUR/kWh
O&M cost	2%
Discount rate	4%
Lifetime	20 years
AEP	IEC certifications
Energy loss	5%
Tax depreciation	10 years
Environmental investment	30%
Cost of electricity	0.19 EUR/kWh
Green certificates	83 EUR/MWh
Green certif. duration	10 years
Superdeductibitility	13.5% × investment cost
Superdeduc. year	2nd year
Tax rate	33.99%
Feasibility study	15,000 EUR
Environm. Invest. max	80,000 EUR

Table 2 Economic parameters calculated for a 3 kW turbine, based on the Belgian incentives. Left results do not consider the cost of the feasibility study (about 15,000 EUR)

3 kW turbine	4 m/s	5 m/s	6 m/s	4 m/s	5 m/s	6 m/s
AEP (kWh)	3210	5870	8375	3210	5870	8375
LCOE (EUR/kWh)	0.51	0.28	0.20	0.95	0.52	0.36
DPP (years)	above 20	10.2	6.7	above 20	above 20	above 20

Table 3 Economic parameters calculated for a 5.2 and a 10 kW turbine, based on the Belgian incentives. These results consider the cost of the feasibility study (about 15,000 EUR)

5 and 10 kW turbines	4 m/s	5 m/s	6 m/s	4 m/s	5 m/s	6 m/s
AEP (kWh)	4629	8949	13882	24590	37360	47240
LCOE (EUR/kWh)	0.93	0.48	0.31	0.28	0.18	0.15
DPP (years)	above 20	above 20	12.0	9.5	6.2	4.9

10 kW turbine has not been studied yet, and it might be that such a project is not feasible. Results of the 3 turbines can be seen in Tables 2 and 3.

Regarding the 3 kW turbine, one must reach at least 6 m/s to get an equivalent LCOE than the network. The discounted payback period is reasonable for the two largest wind speeds, but remains low compared to another renewable energy production system, say photovoltaic. The 5 kW turbine does not show better results than the 3 kW turbine. However, the 10 kW turbine presents some convincing results. For

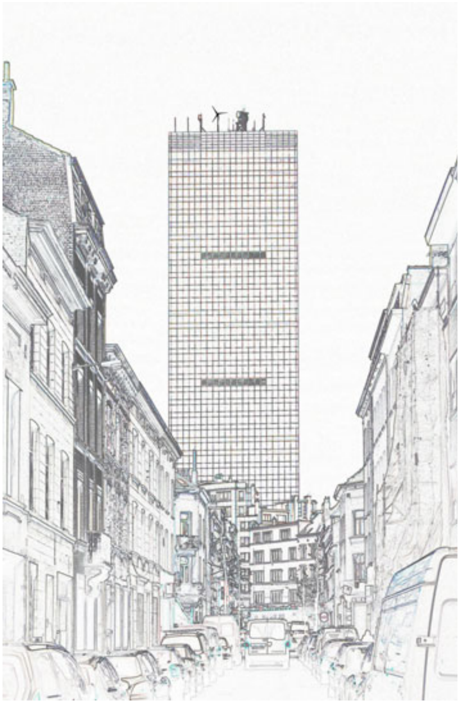


Fig. 12 Mock-up of a wind turbine installed on the South Tower

expected wind speeds on top of the tower (between 5 and 6 m/s), the LCOE is much lower and the payback period is below 7 years. Although these are good results, one must verify the structural integrity of the building for such a machine.

2.5 Building Permit and Future Installation

In addition to the usual documents asked by the Brussels Region, we provided the complete feasibility study of the tower, some mock-ups (Figs. 11 and 12) as well as the agreement of the Brussels airport. The building permit for the first small-building mounted wind turbine in the Brussels Region was submitted in February 2017. Both the Region and the commune granted the permit in November 2017. The future challenges are the development of technical specifications for the public offer. The technical service of the South Tower wishes to install the turbine by the end of 2018.

2.6 Summary of the Approach

In the previous subsections, we review the feasibility of a small building-mounted WT on the South Tower in Belgium. For any future projects, we recommend to follow this approach to ensure a good operation of the turbine and the safety of its environment. These criteria are essentials to promote small building-mounted WT in the future. Here is a summary of the complete study and its different objectives.

Micro-siting gives the optimal locations to install the turbine, as well as the minimal height of the hub to avoid the turbulence zone. If time permits, measuring the wind conditions on the site ensures an accurate prediction of the energy production of the turbine. The stability study must confirm that the building can support the extra loads induced by the turbine installation. Reinforcements of the building might be required. This study also verifies that the vibrations of the turbine will not be perceived by the building's users. The impacts on the turbine's environment are then assessed (noise, shadow flicker, visual, biodiversity and air traffic). All these assessments are crucial to avoid potentially harmful installations. Finally, it can be of interest to perform an economic study of the project. An economically viable project can be better perceived by future investors and the public.

3 Conclusions

This paper reviews the full feasibility study for the installation of a small wind turbine of 3 kW on the South Tower, the tallest building in Belgium. Throughout this study, we demonstrated that the global impacts of the turbine on its environment are weak, if not nonexistent. However, even with good wind conditions, the economic viability of the 3 kW turbine is low. When the cost of the feasibility study is included on the total cost, the turbine is not profitable at all. For a 10 kW turbine, the return on investment is much better. The feasibility for such a turbine have not been studied yet and should be carefully done before the installation.

For the smallest turbine, this poor return on investment illustrates that incentives provided by the Region remain too low. Comparing the incentives for the wind turbines and the photovoltaic panels, one realises that the two technologies do not benefit from the same chances. As mentioned in the introduction, the market is still evolving and the costs are decreasing. Therefore one can soon expect a better future for the wind turbines installed in urban areas.

Nevertheless, a small building-mounted wind turbine in urban areas can provide other benefits than profitability, i.e., raise awareness about renewable energy and underscore the building's sustainability commitment. These benefits are tangible but are complex to quantify in monetary terms.

For future installations, the remaining challenges are the reduction of the total project cost, mainly by lowering the research costs, and help the government to develop a clear legal framework to prevent hazardous installations.

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