TEMPLETECH LTD

Analysis of Wind at Foster's Mill

Version: 02.1

Date: 8th August 2017

Author: SteveTemple

Templetech Ltd

10 Cambridge Road

Impington

CB24 9NU

Incorporated in England and Wales, registered No: 06437133, registered office as above

1. Background and Summary of Analysis.

Foster's Mill at Swaffham Prior in Cambridgeshire is a Grade II* working windmill. The owner currently grinds 20 - 25 tonnes of grain annually under wind power. Because of development of the village over the last 100 years, the wind currently available to the mill is much reduced by the presence of houses and trees close to the mill. In its heyday, the mill stood in open fields with the village largely to the north west and over a hundred yards away. With the prevailing south westerly winds, milling was possible on approximately 130 days per year when the wind speed was greater than 5.9 metres per second (mps), this being the threshold at which sufficient power was available to allow operation of one of the two stones. From records at neighbouring mills, it would have been possible then to grind around 150 tonnes pa.

Housing developments since 1900 have reduced this potential capacity such that milling is now only possible on approximately 20 - 25 days per year. Of this time, the summer months account for approximately 25% because of the presence of trees, which generally dominate over the houses in terms of both bulk and height. In winter, the absence of leaves means that the wind can largely pass through the trees and the houses become the dominant obstacles.

Foster's Mill represents one of only 2 currently commercially working, with 4 or 5 potentially working, mills in Cambridgeshire out of an original population of around 800.

Wind obstructions now exist all around the mill except in the east-north-east quarter, where open fields spread towards the Devil's Dyke. It is now proposed to build a housing development in this ENE quarter, and this report analyses what additional reduction in milling capacity will arise should the development be allowed to proceed.

Wind obstructions not only reduce the available wind resource, but also increase turbulence which adversely affects the milling and the wear and tear upon the mill. Recent developments in Orchard Close have demonstrated this effect – the wind from this quarter was already obstructed by the water tower, but the addition of the housing estate has significantly increased turbulence from this quarter, causing the mill to shudder and shake when the wind blows from the SW, making milling significantly more difficult and further reducing its output.

In summary, the mill has lost 84% of the wind available to it in former times, and will lose a further 22% of what remains should the development go ahead. All of the wind available from all quarters in these circumstances will be turbulent, leading to further losses which are difficult to estimate, but which, based upon the experience of the owner in relation to the recent development in Orchard Close, will be significant.

2. Wind Analysis

There is no established standard in the UK for analysing the wind flow to an existing windmill. Much work has been done on turbines, but these are generally much higher than old windmills and, of course, are deliberately sited in unpopulated areas. Consequently, there

Templetech Ltd

10 Cambridge Road

Impington

CB24 9NU

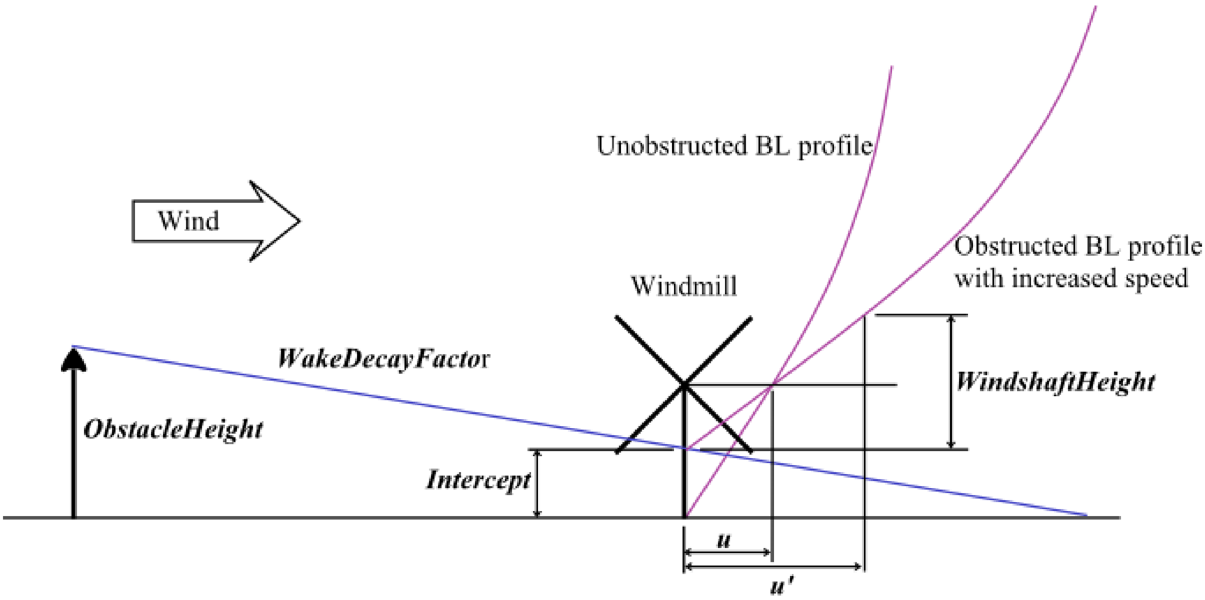
Incorporated in England and Wales, registered No: 06437133, registered office as above

are few sources which show authoritatively what the effect of an obstruction such as a house or a tree is upon the wind flow downstream of the obstacle. Each obstacle produces a wake, similar to that left behind a boat, but governed by different fluid dynamic rules. The wakes spread out and gradually decay, reducing the effective wind speed downstream. The wakes are not smooth, having vortices shedding from the edges of the obstacle and travelling downwind, producing the effect of gustiness. This is referred to as turbulence.

In Holland, in contrast to the UK, there is an established method of assessing the impact of obstacles on the wind flow to windmills. The method is referred to as the "Molen Biotoop" and is fixed as policy in a large proportion of Dutch planning authorities. The method was first developed in the 1940s and has been tested both in wind tunnels and in the field and proven to give a realistic assessment of the effects. To my knowledge, no such long historical verification has been applied to any other model of this particular aerodynamic problem, and I would submit that it should be taken as the most authoritative method for predicting the effects of building developments upon the wind resource of wind mills.

2.1 Methodology

The Molenbiotoop defines how to calculate the effect on the wind flow of an obstacle placed at a distance from a windmill.



Molenbiotoop Explanation

The purple lines represent the "boundary layer" - the velocity of the wind versus height from the ground. The effect of an obstacle is to raise the apparent ground level, so that the boundary layer is lifted up, and the wind mill then experiences a reduced velocity, and the unobstructed wind speed has to be higher in order for the mill to operate. The blue line represents the way in which the boundary layer recovers downstream of the obstacle. From simple parameters, the height of the obstacle, the distance from the mill and the height of the mill, the reduction in velocity can be calculated and hence the necessary increase to enable

Templetech Ltd
10 Cambridge Road
Impington
CB24 9NU

milling from ***u*** to ***u'*** in the general wind speed. It is this value that has been widely tested. From knowledge of the distribution of wind velocity, the proportion of time during which the wind blows at more than the minimum speed to operate the mill can be determined for any obstacle.

The starting point for a full assessment of the available wind is a "wind rose", which shows the time and speed at which the wind blows from every direction towards the mill. An "obstacle rose" is then required, showing the height and distance from the mill for every dominant obstacle in every direction. Obstacle roses are required for "before" and "after" the proposed development takes place, and for each of these, a "summer" and "winter" one to take into account the trees – four different roses in all. "Dominant" means the obstacle which subtends the highest angle in the given direction and which therefore contributes the highest wake. For each obstacle and wind direction, the molen biotoop calculation is then applied to determine firstly the necessary increase in speed, and then the time during which the wind speed exceeds the minimum required for milling. The results of these calculations are then displayed as a "milling rose" to show the total availability of wind for milling. From the 4 milling roses, deductions as to the loss of time caused by the proposed development can be made. It is also useful to include "unobstructed" milling roses for summer and winter, showing how the mill would have operated in former times and the degree to which existing buildings and trees have reduced its potential capacity.

3. Analysis for Foster's Mill

3.1 Data for the Mill

The mill has the sail shaft at a height of 11.8 m, and a sail diameter of 18.67 m. It is generally reckoned that one stone requires about 10 HP (7.46 kW) at its shaft. Overall efficiency of typical mills is about 22% - made up of an established efficiency of 59%, representing the maximum power that can be extracted from a perfect propeller (the "Betz" coefficient), a general aerodynamic efficiency of 30% (arising because the blade shape of an ancient windmill is far from the ideal which would be seen in a modern wind turbine) and a mechanical efficiency of 50% due to losses from friction in the bearings and gears – also far from a modern ideal. This means that the minimum wind speed at the sail shaft to enable one stone at Fosters to grind is about 5.9 m/s or 13 mph. This figure accords with the owner's measurements using an anemometer. The owner also reports that the maximum speed at which it is practical to work is about 15 m/s or 34 mph, but the wind rarely reaches this speed and virtually never when increased wind speeds are needed to achieve the minimum power requirement.

3.2 Wind Rose

Wind data is available from local airfields where the speed and direction of the wind is recorded, typically on an hourly basis, throughout the year. Obviously, the further the mill is from the airfields, the less accurate this data will be. Foster's mill is between Cambridge

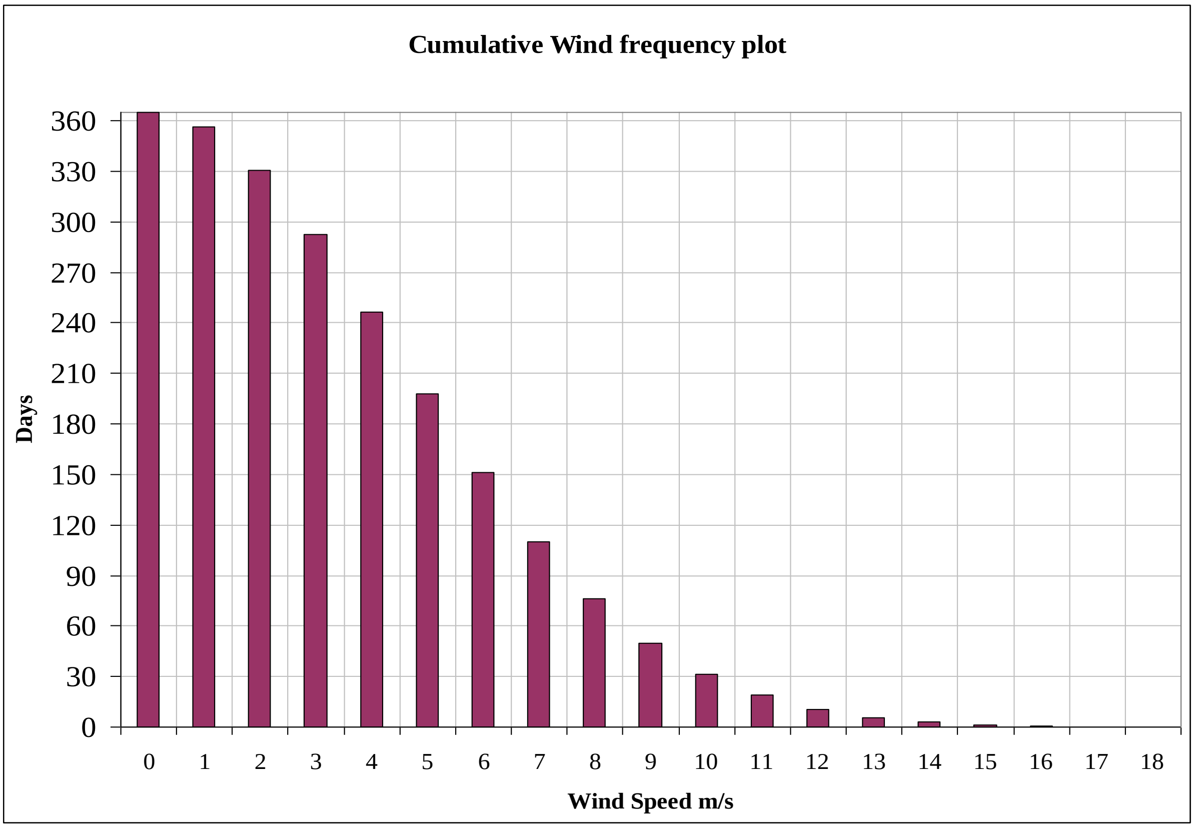
Templetech Ltd
10 Cambridge Road
Impington
CB24 9NU
Incorporated in England and Wales, registered No: 06437133, registered office as above

Airport and Mildenhall RAF station. The wind rose used is from Mildenhall (as being more typical of the terrain surrounding the mill), supplied by Iowa State university, and covering the 6 years from 2011 to 2017. The average wind speed recorded is 4.5 m/s at a height of 10 m over the 6 year period.

The wind roses have been checked for both summer and winter months and no significant difference has been found, so the full year averages over the whole period of data collection have been used.

3.3 The Rayleigh Distribution of Wind Speed

Statistically, all wind roses closely fit the cumulative Rayleigh distribution (which is itself a special case of the Weibull distribution), shown below. This has been plotted for a 4.4 m/s average.



Given this, the time for which the wind blows at speeds between the minimum and maximum for milling can be calculated from a formula using the overall average speed for all directions and the percentage of time during which the wind blows for each direction.

The increased minimum speed for each direction, taking into account upstream obstacles, is calculated from the Molenbiotoop formula, and therefore modifies the total number of days available from the direction of the obstacle. It is calculated by reading from the graph above the cumulative days available at the modified minimum speed. The maximum speed is rarely achieved, but such time that is available at greater speed than the maximum is subtracted.

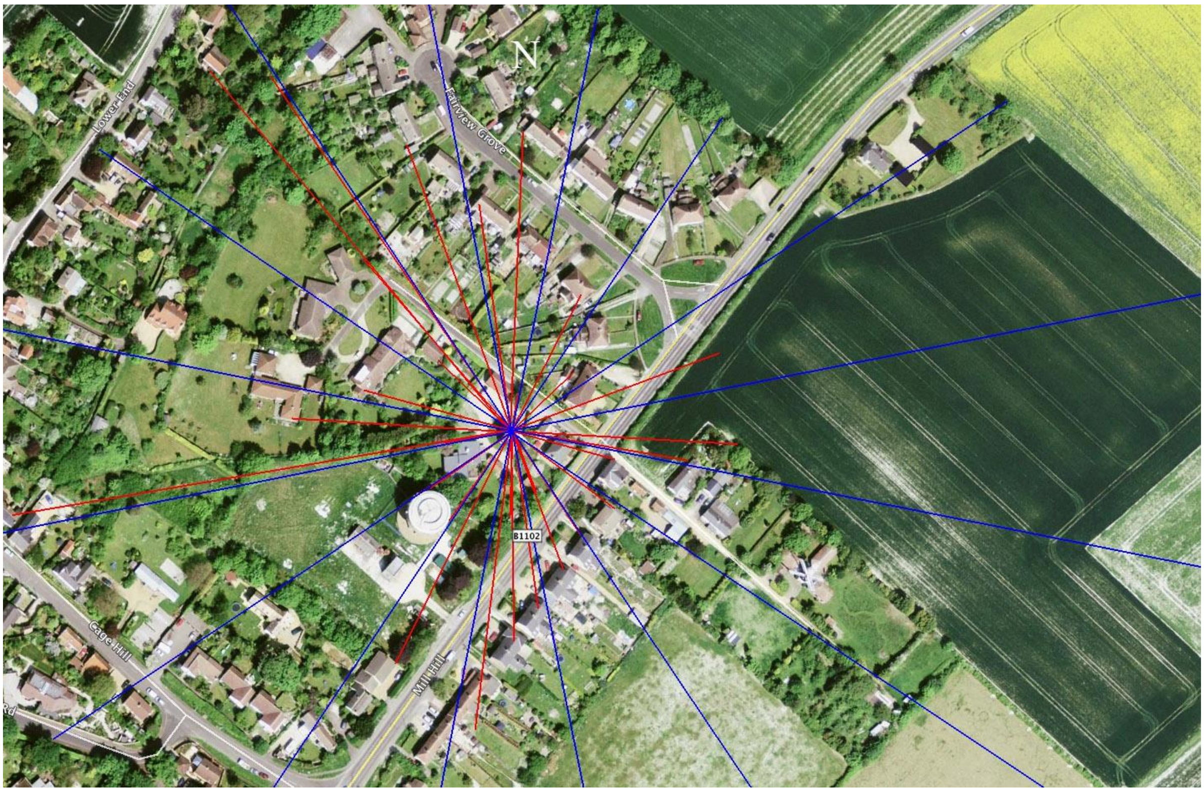
Templetech Ltd
10 Cambridge Road
Impington
CB24 9NU

3.4 Obstacles

The obstacle rose is derived from a combination of data sources. It is plotted on an aerial view showing the mill and its environs stretching out at least 400 m from the mill (400 m being the maximum distance considered in the molen biotoop). Lines are drawn radiating from the mill and terminating at the first edge of each obstacle taken in a clockwise direction. For each obstacle, its height, the distance to it and the direction are noted. These values are tabulated in a spreadsheet together with the points of the compass representing the divisions of the given windrose – in this case, the midpoints between 16 compass points, N, NNE, NE etc. The directions and distances are obtained from a Google Earth view.

The obstacles chosen are those which subtend the highest angle from the mill. This is best done from photographs taken all round the mill as shown below. This sequence is missing the quarter of the proposed development because the mill happened to be pointing in that direction when the photographs were taken, but this quarter is open at present and contains no additional obstacles that are not apparent in the photo.

Below is shown the Google Earth view of the obstacle rose.

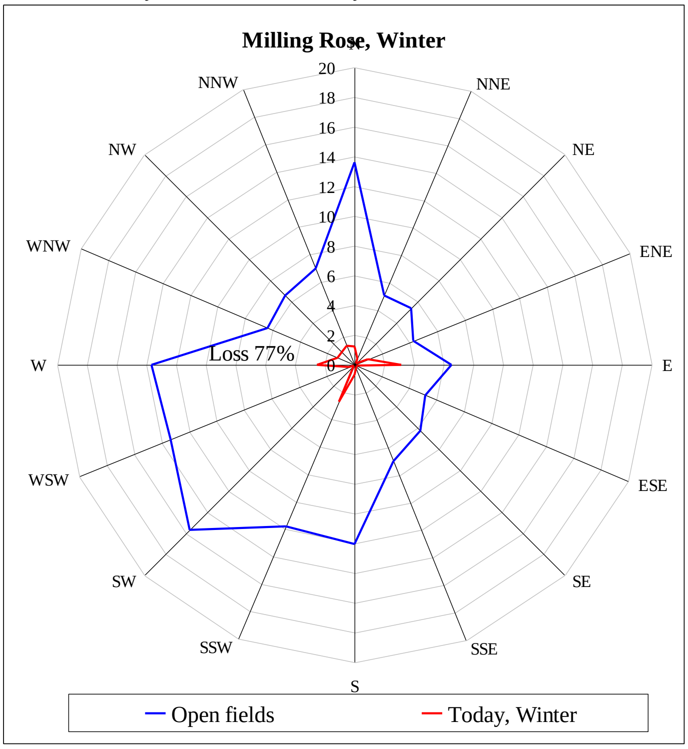


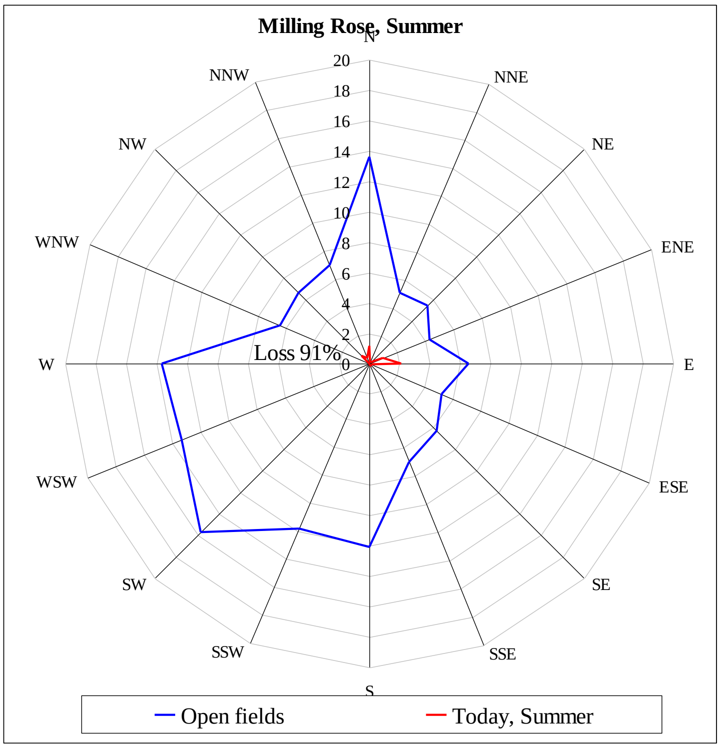
The blue lines are the compass points corresponding to the mid points of the sixteenths of the wind roses. In this view, the area covered by the proposed development is the dark green field to the right. The two red lines extending into the field represent the edges of the existing obstacles that bound the new development from the viewpoint of the mill, and it is assumed that the bungalows to be built will fill this space at a distance of 95 m from the mill and with a 4.5 m roof height.

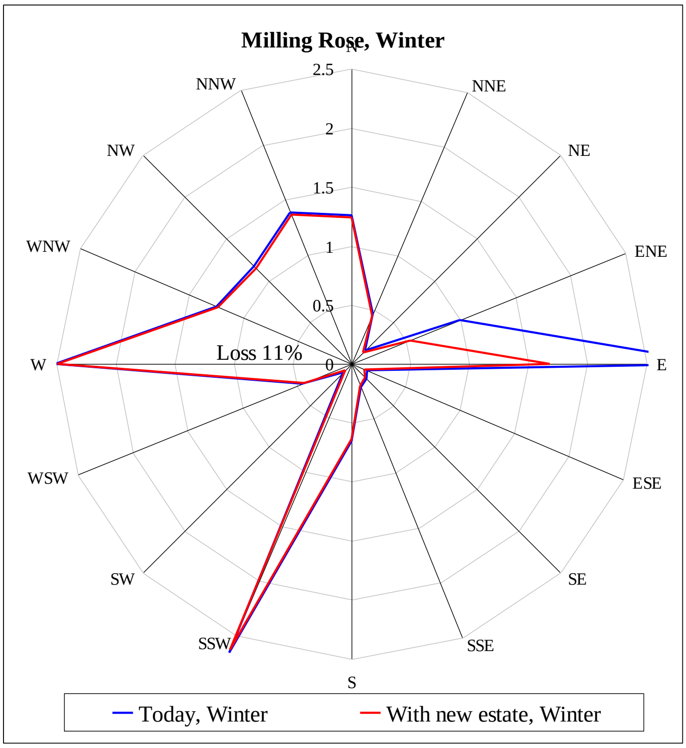
Templetech Ltd
10 Cambridge Road
Impington
CB24 9NU
Incorporated in England and Wales, registered No: 06437133, registered office as above

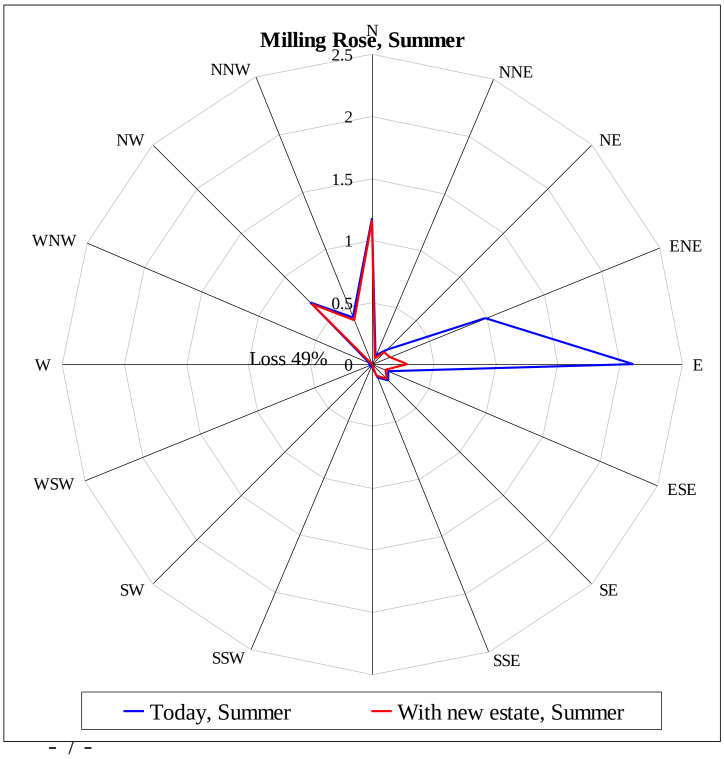
4. Analytical Results

Below are shown the resulting milling roses as described above. The radial axes units are days, and for clarity the scale of these axes is larger in the second pair of graphs.









The “Losses” shown in the graphs refer to the difference in total time available for milling between the two plots – effectively (blue curve – red curve) – in each case.

In summary, the mill has lost 91% of its formerly available milling capacity, and the development will further reduce potential milling time by 22%. It has been assumed that the development will eventually include ornamental trees up to a height of 7 m, over-topping the proposed 4.5 m height of the buildings. Consequentially, the greater proportionate loss of time will occur during the summer months with approximately 49% loss amounting to 3.2 days out of 6.3 currently available, whilst the winter loss will be about 11%, 1.9 days out of 16.4.

No attempt has been made to estimate losses and other effects due to turbulence because no realistic data is available for this aspect. However, general experience of operation of old windmills is that both effects are significant.

Steve Temple

BA, FRSA

Templetech Ltd

10 Cambridge Road

Impington

CB24 9NU