



# ESDU 88038

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## Estimation of hours per year when mean wind speed exceeds specified thresholds

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## THE PREPARATION OF THIS DATA ITEM

The work on this particular Data Item was monitored and guided by the Wind Engineering Panel. This Panel, which took over the work on wind engineering previously monitored by the Fluid Mechanics Steering Group, first met in 1979 and now has the following membership:

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## ESTIMATION OF HOURS PER YEAR WHEN MEAN WIND SPEED EXCEEDS SPECIFIED THRESHOLDS

### CONTENTS

|                                                                                                            | Page |
|------------------------------------------------------------------------------------------------------------|------|
| 1. NOTATION                                                                                                | 1    |
| 2. INTRODUCTION                                                                                            | 2    |
| 3. APPLICABILITY OF THE METHOD AND CALCULATION PROCEDURES                                                  | 3    |
| 3.1 Applicability                                                                                          | 3    |
| 3.2 Assumptions                                                                                            | 3    |
| 3.3 Input Data Required                                                                                    | 4    |
| 3.3.1 Estimation of $U$ for known extreme wind speed                                                       | 4    |
| 3.4 Procedure for Calculating Wind Frequency Distribution from Known Extreme Mode, $U$                     | 5    |
| 3.4.1 All directions                                                                                       | 5    |
| 3.4.2 Sector                                                                                               | 5    |
| 3.5 Extrapolation to Other Heights and Terrain                                                             | 6    |
| 3.6 Tentative Procedure for Wind Climate with Two Principal Storm Mechanisms (All-Directions Case)         | 7    |
| 4. EXAMPLE                                                                                                 | 7    |
| 5. DERIVATION OF THE BASIC METHOD                                                                          | 10   |
| 5.1 Relationship Between Extreme Values Parameters ( $U$ , $\alpha$ ) and Weibull Parameters ( $c$ , $k$ ) | 11   |
| 5.2 Estimation of Hours of Wind from Individual Sectors                                                    | 13   |
| 5.3 Comparison with Measured Data                                                                          | 14   |
| 6. REFERENCES                                                                                              | 14   |

## ESTIMATION OF HOURS PER YEAR WHEN MEAN WIND SPEED EXCEEDS SPECIFIED THRESHOLDS

### 1. NOTATION

|                      |                                                                                                                                         | Units              |                     |
|----------------------|-----------------------------------------------------------------------------------------------------------------------------------------|--------------------|---------------------|
|                      |                                                                                                                                         | SI                 | British             |
| $c$                  | Weibull scale parameter (Equation (3.3))                                                                                                | m/s                | ft/s                |
| $H$                  | hours per year when wind speed exceeds level $V$                                                                                        | hr/yr              | hr/yr               |
| $K_s$                | factor giving $V/V_r$ or $c/c_r$ from ESDU 84011 <sup>5</sup>                                                                           |                    |                     |
| $k$                  | Weibull shape parameter (Equation (3.3))                                                                                                |                    |                     |
| $N_V$ ,<br>$N_{V^2}$ | number of upcrossings per unit time for a threshold $V$ and $V^2$ respectively                                                          | cycle/yr           | cycle/yr            |
| $n_s$                | average number of storms per year                                                                                                       |                    |                     |
| $P_V$                | probability of wind speed being less than a value $V$                                                                                   |                    |                     |
| $P_x$                | probability of wind speed being less than a value $x$ in any one year, $P_x = 1 - 1/T$                                                  |                    |                     |
| $T$                  | mean recurrence interval or return period: $T = 1/(1 - P_x)$                                                                            | yr                 | yr                  |
| $t$                  | average number of hours of wind per year                                                                                                |                    |                     |
| $t'$                 | uncorrected value of $t$ , see Section 5.2                                                                                              |                    |                     |
| $U$                  | mode of extreme value distribution of $V^2$ (Equation (3.1))                                                                            | (m/s) <sup>2</sup> | (ft/s) <sup>2</sup> |
| $U_\theta$           | value of $U$ for wind direction $\theta$ , obtained by independent analysis of wind speed maxima in sector $\theta$ (see Section 3.3.1) | (m/s) <sup>2</sup> | (ft/s) <sup>2</sup> |
| $U_V$                | mode of extreme value distribution of $V$                                                                                               | m/s                | ft/s                |
| $V$                  | hourly-mean wind speed                                                                                                                  | m/s                | ft/s                |
| $V_T$                | extreme value of $V$ with mean recurrence interval $T$                                                                                  | m/s                | ft/s                |
| $x$                  | equated to individual maximum values of $V^2$                                                                                           | (m/s) <sup>2</sup> | (ft/s) <sup>2</sup> |
| $y$                  | reduced variate; $y = -\ln(-\ln P_x)$                                                                                                   |                    |                     |
| $z$                  | height above ground                                                                                                                     | m                  | ft                  |
| $z_0$                | terrain roughness parameter (see ESDU 82026 <sup>3</sup> )                                                                              | m                  | ft                  |

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1

|            |                                                                            |                   |                   |
|------------|----------------------------------------------------------------------------|-------------------|-------------------|
| $\alpha$   | reciprocal of dispersion parameter for extreme value distribution of $V^2$ | $(\text{s/m})^2$  | $(\text{s/ft})^2$ |
| $\alpha_V$ | reciprocal of dispersion parameter for extreme value distribution of $V$   | $\text{s/m}$      | $\text{s/ft}$     |
| $\sigma_V$ | standard deviation of $V$                                                  | $\text{m/s}$      | $\text{ft/s}$     |
| $v_0$      | mean crossing rate of $V$ (Equation (5.9))                                 | $\text{cycle/yr}$ | $\text{cycle/yr}$ |
| $\theta$   | mean wind direction in sector                                              | $\text{degree}$   | $\text{degree}$   |

## Subscripts

|          |                                                           |
|----------|-----------------------------------------------------------|
| $A, B$   | relate to storm mechanisms $A$ and $B$                    |
| $all$    | relates to values for all directions taken together       |
| $r$      | refers to value for basic data conditions                 |
| $T$      | refers to value for mean recurrence interval of $T$ years |
| $\theta$ | refers to value for wind direction $\theta$               |

## 2. INTRODUCTION

Recordings of wind speed at regular intervals are made at meteorological stations in many parts of the world. These records are used in two principal ways.

Firstly, the wind speed maxima in the form of annual maxima, or individual storm maxima, are extracted and extreme value analysis methods, such as described in ESDU 87034<sup>8</sup>, are used to derive extreme value distributions from which estimates of design wind speeds for specified mean recurrence intervals (often termed return period) can be made. Extreme wind speeds are required in structural design to establish maximum wind loading criteria. Because of this need extreme wind speed data are available for many regions of the world in the form of standard maps, tables or individual site records.

In the second case, continuous wind speed records are used to establish the frequency of occurrence of wind speeds at thresholds lower than the extreme values typical of a 50-year mean recurrence interval. This information usually takes the form of hours in a year when the hourly-mean wind speed is above a specified level or threshold. These data are required for serviceability criteria such as for building ventilation and occupant comfort, also for pollution studies and they are of particular interest when assessing wind energy potential at various sites. Such information is not as readily or generally available as the extreme value data.

The purpose of this Data Item is to give a method by which the wind speed frequency distribution may be estimated when only the extreme value mode parameter,  $U$ , is known for a particular site. The method applies to the case when winds from all directions are combined together and also to wind directions within individual sectors (usually 30°) providing the corresponding extreme value mode parameters ( $U_\theta$ ) are known or can be estimated.

The calculation procedure of the method and its applicability are described in Section 3 and illustrated by an example in Section 4. The background and derivation of the method are summarised in Section 5. The method may also be used inversely to estimate extreme wind speeds from known parent distribution parameters obtained from hours of wind above specified thresholds. This can be especially useful when attempting to predict a design wind speed for a site with unusual features using only several years of measurements. A procedure for this situation is described in ESDU 87034<sup>8</sup> and an example is given in ESDU 88037<sup>10</sup>.

## 3. APPLICABILITY OF THE METHOD AND CALCULATION PROCEDURES

### 3.1 Applicability

The derivation of the basic method is described in Section 5. It is applicable to the following.

- (a) A wind climate essentially dominated by frontal depressions or extra-tropical storms.
- (b) The same height above ground and terrain roughness and topography applicable to the site for which the extreme value distribution parameters are available.
- (c) The all-directions case when all wind speeds at a site are grouped together (irrespective of direction).
- (d) Wind speeds from any sector.

The basic method can be extended to apply to the following situations.

- (i) Other heights and terrain roughness than those applicable to the basic data (Section 3.5).
- (ii) Sites with 'simple' topographic features such as an isolated hill when the basic data apply only to flat terrain (Section 3.5).
- (iii) Tentatively, the method can be extended to wind climates with two principal storm mechanisms such as frontal depressions and thunderstorms (Section 3.6).

### 3.2 Assumptions

The following basic assumptions apply for the reasons explained in Section 5.

- (a) The extreme value distribution of mean wind speed is represented by the Fisher-Tippett Type 1 distribution

$$x_T = U + (1/\alpha)y \quad (3.1)$$

where  $y = -\ln[-\ln(1 - 1/T)]$ . (3.2)

As explained in ESDU 87034 and Section 5.1, a better fit of Equation (3.1) to wind speed maxima is obtained using  $x_T = V_T^2$  where  $V_T$  is the extreme wind speed with a mean recurrence interval of  $T$  years. However, many past analyses of extremes have been performed using  $x_T = V_T$  to obtain the corresponding parameters  $U_V$  and  $\alpha_V$ . In this case a satisfactory approximation is to take  $U = (U_V)^2$  and  $U\alpha = 0.5 U_V\alpha_V$ .

- (b) The 'parent' distribution of mean wind speed (*i.e.* the frequency distribution given by the number of hours per year ( $H$ ) when the wind speed is greater than particular levels) is represented by the Weibull distribution

$$P_V = 1 - \exp[-(V/c)^k] \quad (3.3)$$

so that 
$$H = \exp[-(V/c)^k] \times t. \quad (3.4)$$

- (c) The Weibull parameter,  $k$ , is assumed to be independent of terrain roughness and height above the ground up to about 100 m. Note that these assumptions do not apply to the Weibull parameter  $c$ .

### 3.3 Input Data Required

To calculate the hours per year when the wind is above specified thresholds for a site with a known extreme value distribution, all that is required is the value of the mode,  $U_{all}$ , for the all-directions case and  $U_\theta$  for individual wind directions (these are normally grouped in  $30^\circ$  sectors, between  $0^\circ$  and  $360^\circ$ ).

If values of  $U_V$  instead of  $U$  are available (see Section 3.2a) then it may be assumed that  $U \approx (U_V)^2$ . If a value of  $U$  or  $U_V$  is not available directly then Section 3.3.1 provides some guidance on estimating a value.

Additionally, a value of the Weibull parameter  $k$  is required. In most cases it is sufficient to assume a value of 1.85 but if there is evidence to suggest a different local average value (different by more than about  $\pm 0.1$  in  $k$ ) then this value can be used instead.

Where data for a mixed wind climate are required it is also necessary to obtain an estimate of the annual storm rate,  $n_s$ , of each principal storm mechanism.

#### 3.3.1 Estimation of $U$ for known extreme wind speed

If values of the mode parameter  $U$  are not available for the site in question then it may be possible to estimate a value from a known or estimated extreme wind speed for the site.

For a given extreme wind speed,  $V_T$ , (or an estimated value\*) the mode  $U$  can be obtained from the Fisher-Tippett Type 1 distribution

$$U = V_T^2 + (1/\alpha) \ln[-\ln(1 - 1/T)] \quad (3.5)$$

or 
$$U = \{V_T + (1/\alpha_V) \ln[\ln(1 - 1/T)]\}^2 \quad (3.6)$$

depending on whether  $V_T^2$  or  $V_T$  maxima, respectively, were used in the extreme value analysis (see Section 3.3). Values of  $U\alpha$  for a geographic region, such as the UK, are usually approximately constant. For frontal depression storms  $U\alpha \approx 5$  or  $U_V \alpha_V \approx 10$ . The extreme wind speed usually available is for  $T = 50$  years so that

$$U = \frac{V_{50}^2}{1 + 3.9/(\alpha U)} \quad (3.7)$$

or 
$$U = \left[ \frac{V_{50}}{1 + 3.9/(\alpha_V U_V)} \right]^2. \quad (3.8)$$

\* Estimated values of  $V_T$  should be adjusted by factors for the actual height, local terrain roughness changes and topography. Such factors are given in ESDU 82026<sup>3</sup> and 84011<sup>5</sup> or by the program described in ESDU 87006<sup>7</sup>.