TORNADO RATING IN EUROPE WITH THE EF-SCALE

DEFINITION OF SPECIFIC DAMAGE INDICATORS FOR ACCURATE TORNADO RATINGS IN EUROPE

Damage caused by the Hautmont EF4 tornado of August 3, 2008 (France). © P. Mahieu, E. Wesolek

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INTRODUCTION

Nothing beats a Damage Scale for analysing damages. The Tornadoes and Severe Storms French Observatory (KERAUNOS) used this simple starting point in 2009 when choosing to use the Enhanced Fujita scale (EF-scale) to assess the intensity of tornadoes in France. The EF-scale as we shall see, is the only real scale adapted to measuring the damage caused by tornadoes, as opposed to the original Fujita scale (F-scale) which is purely a wind speed scale whose application raises several difficulties.

Use of the EF-scale outside America, where it was designed, must nevertheless be adapted. This is what led KERAUNOS in 2009 to propose several adjustments designed to make the scale more relevant in a European context. These adjustments were the subject of an initial presentation carried out in 2011 during the 6th European Conference on Severe Storms (ECSS), at Palma, Majorca.

Since then, after nine years of consistent use, and proven use on several hundred tornado cases, the validity of this approach of European adaptation of the EF-scale has now sufficiently proven its worth to be able to offer this detailed publication. Its aim is to extend beyond French borders and to make tornado ratings more accurate and easier across the whole of Europe, which has largely homogeneous construction methods and vegetation. Some of these indicators can even be relevant and useful on other continents. The area of application of this research is therefore very broad.

This publication initially aims to clarify the choice that was made to use the EF-scale in the process of recording tornado intensity in France, unlike many other European countries and the European Severe Storms Laboratory (ESSL), where the use of the original Fujita scale (F-scale) and the Torro scale (T-scale) is still the norm. It will then present the methodology developed to extend the EF-scale to the specific conditions found in Europe. Finally, the specific indicators set out within this framework are detailed in order to be usable as daily tools for rating tornadoes throughout Europe.

This publication does not claim to be definitive, and may be occasionally updated, especially when particularly intense tornadoes reach hitherto undocumented damage indicators. These updates are listed in the background section on the last page of this publication.

Finally, generally speaking, the authors, through this publication, would like to contribute to making the EF-scale a truly international scale, the only solution if we are to achieve homogeneous climatology study into tornado intensity around the world. We hope that this publication will inspire similar work on other continents.

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1 – WHY THE EF-SCALE?

This question may seem surprising at a time when the EF-scale has been for many years considered as the reference in the United States and Canada. This is not the case in Europe however, where this scale has encountered some resistance, the use which KERAUNOS has made of it in France being the exception to this rule. It seems therefore useful to clarify the reasons for this choice here.

HOW IS A TORNADO'S INTENSITY MEASURED?

To understand KERAUNOS's choice of using the EF-scale, it is useful to return to the fundamental question which concerns us: how *exactly*, *accurately*, is the intensity of a tornado assessed?

This question immediately comes up against an answer that defies science. In fact, a direct and objective measurement of wind speeds at the centre of a tornado is extremely rare; not an ideal situation for a physical phenomenon that we are attempting to study scientifically. This state of affairs can be explained twofold: firstly, the probability of finding a measuring instrument positioned by chance in the narrow trajectory of a tornado is extremely low; secondly, even if this were to occur, it is likely that the anemometer would be severely damaged and would therefore be incapable of accurately measuring the maximum wind speed in the centre of the vortex.

Even if these two constraints were removed and a measurement was to be taken, it is not certain that it would represent the maximum wind value generated by this tornado. A tornado is, by its very nature, an extremely turbulent wind vortex, especially close to the ground, with both vertical and horizontal wind components that are constantly evolving, and wind speeds which vary at all points of its trajectory according to the roughness of the terrain and the obstacles in its path. Taking an accurate and representative wind speed measurement in these conditions is a real challenge.

The alternative which consists of measuring winds at a distance using a Doppler radar has already provided some interesting results (Wurman, 2005). Nevertheless, winds close to ground level are difficult to assess using this type of instrument, and in any case it is currently impossible to measure in this way consistently, due to the high cost and complications involved in installing mobile Doppler radars.

In conclusion, it would seem to be near-impossible to consistently and objectively measure the speed of the wind at the vortex of a tornado. So, faced with this problem, what solutions are available? The only solution consists of evaluating the intensity of the tornado after it has occurred by a detailed ground survey. The goal is to record the damages left by the tornado, to let them speak for themselves. From this analysis we can deduct the probable wind speed generated by the vortex, by determining the wind speed beyond which certain damage is caused. This deductive analysis should not however be carried out in an approximate way. A frame of reference is essential: this is where a *scale* come into the picture.

THE CRITERIA FOR A GOOD SCALE

A scale which allows damage observed on the ground to be converted into tornado wind speeds is vital in order to be able to reliably determine maximum wind intensity. What can be expected of a scale of this kind?

- It should be *suited to its use*, that is, among its key features should be *categories of damage*. This is an essential methodological principle, since only the damages on the ground will be assessed and analysed.

- It must offer estimations of wind speed which are *calibrated*, empirically checked and validated by specialists. This element gives the scale its scientific validity.

- It must reason in terms of *speed ranges* rather than fixed thresholds, as it is clear that certain types of damage are not always produced at exactly the same wind speeds. The duration of violent winds (dependent on the width of the tornado and its translation speed), the weak points of buildings affected, the volume of debris swept up by the tornado,… : all these elements should be taken into account when assessing the breaking point of elements hit and consequently on the associated wind speeds.

- Finally, it must be *concise*, to avoid getting lost in irrelevant details. Each incident of damage is unique in its characteristics, and it is not desirable to try to cover every eventuality. The scale must therefore set the broad lines of analysis, the main damage categories; it is up to the experts on the ground to add the necessary nuances and adjust the conclusions to the reality of the terrain.

The question remains however: which scale best addresses these criteria? To date, there are three potentially suitable scales: the Fujita scale (F-scale), the Torro scale (T-scale) and the Enhanced Fujita scale (EF-scale). In order to see this more clearly, the characteristics of each scale are detailed below.

THE F-SCALE: A WIND SPEED SCALE

The first scale dedicated to tornadoes was designed in the United States by Dr T. Theodore Fujita, who was among the most reputed experts of the age in this area. This wind speed scale was developed firstly in collaboration with Pearson (Fujita-Pearson scale), before becoming known under the name of Fujita scale, or F-scale.

The idea emerged at the end of the 1960's and the first formulation dates back to February 1971 in a publication by the University of Chicago (Fujita, 1971). The idea consists of linking the Beaufort scale (force 12, hurricane) to the speed of sound (Mach 1), by developing a scale composed of 12 levels. Thus, level F1 corresponds to force 12 on the Beaufort scale and level F12 to Mach 1. To these 12 grades, Fujita added a level F0 to take into account the weakest tornadoes, whose winds are estimated to be below force 12 on the Beaufort scale.

Although the Fujita scale has 13 levels, its use is limited in reality to levels F0 to F5. In fact, Fujita considers that F6 wind speeds, even if they are judged to be exceptionally possible, are nevertheless highly unlikely. Fujita therefore categorizes tornadoes of the 6 first degrees of

the scale, associating them empirically with certain types of damages: F0 (very weak), F1 (weak), F2 (strong), F3 (severe), F4 (devastating) and F5 (incredible).

The detail of the F-scale is presented below (Fujita, 1971):

F-SCALE	WIND SPEED	TYPICAL DAMAGE
F0	< 117 km/h	Light damage. Some damage to chimneys and TV antennae; breaks twigs off trees; pushes over shallow rooted trees.
F1	117 - 180 km/h	Moderate damage. Peels surface off roofs; windows broken; light trailer houses pushed or overturned; some trees uprooted or snapped; moving automobiles pushed off the road.
F2	181 - 253 km/h	Considerable damage. Roofs torn off frame houses leaving strong upright walls; weak buildings in rural areas demolished; trailer houses destroyed; large trees snapped or uprooted; rail road boxcars pushed over; light-object missiles generated; cars blown off highway.
F3	254 - 332 km/h	Severe damage. Roofs and some walls torn off frame houses; some rural buildings completely demolished; trains overturned; steel-framed hangar-warehouse type structures torn; cars lifted off the ground; most trees in a forest uprooted, snapped or levelled.
F4	333 - 418 km/h	Devastating damage. Whole frame houses levelled, leaving piles of debris; steel structures badly damaged; trees debarked by small flying debris; cars and trains thrown some distances or rolling considerable distances; large missiles generated.
F5	419 - 512 km/h	Incredible damage. Whole frame houses tossed off foundations; steel-reinforced concrete structures badly damaged; automobile-sized missiles generated; incredible phenomena will occur.

The F-scale is relevant as a wind-speed scale: indeed, it makes it possible to get rid of the diversity of the modes of construction, to consider only the speed of the wind. In this way, the scale can theoretically apply throughout the world.

But in reality, the wind speed is exactly that unknown quantity that must be determined, and not the data alone which authorises the correct use of the scale. This is a major problem that prevents this wind speed scale from being used as it should: the F-scale is in fact used wrongly as a damage scale, by using the "typical damage" observations to deduct wind speeds. This poses at least two serious problems in rating tornado intensity:

- firstly, the relationship between the wind speeds and the damage caused is largely arbitrary in the F-scale. This uncertainty was already criticised during the 1970's (Minor et al., 1977). The main consequence is that it is hazardous to attempt to deduct a relevant wind speed, and therefore a relevant F ranking, using examples of damage given by the F-scale, since there is no solid link between the two.

- secondly, the F-scale is based mainly on the "well-constructed frame home" to evaluate the degree of damage. This indicator is poorly adapted to Europe, where this type of housing is not the norm.

Note: This is a good opportunity to underline the fact that the use of the EF-scale in Europe is contested due to it being too American in its damage indicators. However the F-scale is just as criticizable, if not more so: we have just seen that the only indicator provided is typically American and not adapted to European construction methods. This fact does not elicit much opposition to the use of the F-scale in Europe which is still the general norm, yet it seems to be a problem for the EF-scale. This difference in judgement and appreciation between the two scales is surprising and detrimental, as the rankings in the F-scale in Europe are fraught with uncertainty for this same reason. Fujita has certainly integrated a posteriori the solidity of buildings affected to judge the level of intensity on the F-scale (1981), but this modulation remains imprecise and uncertain in its practical application.

For these reasons, the F-scale presents serious limitations in *its everyday application* which render it unsatisfactory for accurate tornado ratings.

THE T-SCALE: A WIND SCALE CLOSE TO THE F-SCALE

The Torro scale (T-scale) was first developed in the United Kingdom, where it was first used publicly in 1975. It's method is close to the F-scale, that is, the T-scale is based on the Beaufort scale, which is extended to give a force 30 on the Beaufort scale according to the following formula: $T = (0.5\ B - 4)$. For this reason it claims to be a pure wind speed scale.

Unlike the F-scale which has 6 useful levels, the T-scale has 12, ranging from T0 to T11. Nevertheless, because of their similar design, the two scales overlap by only a few km per hour: T0 and T1 $\simeq$ F0; T2 and T3 $\simeq$ F1 ; etc. The T-scale is therefore considered to be a little like the F-scale split in two.

For this reason, its contribution is extremely limited and the T-scale does not resolve any of the weaknesses inherent in the F-scale. It even tends to exacerbate them as it multiplies the intensity levels, without any calibrated relationship between the damage announced and the wind speeds found on the scale. Added to this is the unreliability of the Beaufort scale, which takes into account average wind speeds over 10 minute intervals, to rank tornado winds, which measure is based on the strongest gust over 3 seconds; this difference in reference point renders the choice of the T-scale scientifically dubious.

The T-scale is currently widely used in the United Kingdom, and is also used as a reference by the ESSL in its ranking of European tornadoes, alongside the F-scale (Groenemeijer, 2013).

THE EF-SCALE: A DAMAGE SCALE

This is the third and last scale in practical use. It originated in the mid-2000's, when the United States undertook a study to find a solution to the limits and approximations of the F-scale. These gave rise to the Enhanced Fujita scale (EF-scale), whose official use began in the United States in January 2007.

The EF-scale marked a change in the way that tornado intensity was assessed. As with the F-scale, it defines 6 levels of intensity, from EF0 to EF5. However, the logic of the original F-scale was entirely reworked, in order to create a new *damage scale*, and therefore avoid the pitfalls of a scale designed purely to measure wind speeds. Its design and structure are twofold:

1 – firstly, 28 *damage indicators* were defined. By this it means the main categories of constructions or vegetation, which are references available during ground surveys to base the damage analysis. The list of these damage indicators is provided below (WSEC, 2004).

DI n°	DAMAGE INDICATOR (DI)	CODE
1	Small barns or farm outbuildings	SBO
2	One- or two-family residences	FR12
3	Manufactured home – single wide	MHSW
4	Manufactured home – double wide	MHDW
5	Apartments, condos, townhouses (3 stories or less)	ACT
6	Motel	M
7	Masonry apartment or motel building	MAM
8	Small retail building (fast food restaurants)	SRB
9	Small professional building (doctor's office, branch banks)	SPB
10	Strip mall	SM
11	Large shopping mall	LSM
12	Large, isolated retail building	LIRB
13	Automobile showroom	ASR
14	Automobile service building	ASB
15	Elementary school (single story, interior or exterior hallways)	ES
16	Junior or senior high school	JHSH
17	Low-rise building (1-4 stories)	LRB
18	Mid-rise building (5-20 stories)	MRB
19	High-rise building (more than 20 stories)	HRB
20	Institutional building (hospital, government or university building)	IB
21	Metal building system	MBS
22	Service station canopy	SSC
23	Warehouse building (tilt-up walls or heavy-timber construction)	WHB
24	Electrical transmission lines	ETL
25	Free-standing towers	FST
26	Free-standing light poles, luminary poles, flag poles	FSP
27	Trees : hardwood	TH
28	Trees : softwood	TS

2 - secondly, several *degrees of damage* were defined for each of these indicators. The degree of damage varies from "no damage" to "total destruction of the indicator". Each degree of damage is associated with a range of probable wind speeds, calibrated by structural engineers, and adjusted according to the degree of solidity of the indicator: low bound, expected and upper bound wind values are therefore provided for each degree of damage.

This method gives a calibrated wind speed range for each degree of damage for each indicator. The reliability of the relationship between the wind speed and the damages is therefore much more accurate.

The main consequence of this calibration is a modification of wind speeds associated with each level of the scale compared with the original F-scale. Progression is significant especially for the levels higher than (E)F2, whereas it is minimal for the lower intensities. This corrects the long-condemned bias inherent in the F-scale, which consisted of associating the

damages with arbitrary and excessive wind speeds. The EF-scale repositions wind speed at levels which are much more likely to be in line with reality.

The table below shows the progression of wind speeds associated with the F- and EF-scales:

F-SCALE	WIND SPEED (F)	EF-SCALE	WIND SPEED (EF)
F0	< 117 km/h	EF0	103 – 137 km/h
F1	117 - 180 km/h	EF1	138 – 177 km/h
F2	181 - 253 km/h	EF2	178 – 217 km/h
F3	254 - 332 km/h	EF3	218 – 266 km/h
F4	333 - 418 km/h	EF4	267 – 322 km/h
F5	419 - 512 km/h	EF5	> 322 km/h

Despite this change in the wind speed ranges associated with each level of the scale, the F-scale and the EF-scale overlap and coincide *if we are reasoning in terms of damages*. For example, damages which would normally warrant an F3 ranking on the old scale would more often than not be ranked EF3 in the new scale. There is some divergence, but the difference in grading generally does not exceed +/- 1 degree on the scale. In other words, as a general rule and in the overwhelming majority of cases, it is possible to consider that EF ≃ F *if we are reasoning in terms of damages*. Therefore, the EF has the advantage of being consistent with the F-scale in the grading of degrees of damage, this avoids any significant departure in climatology terms of tornado intensity when migrating from the F-scale to the EF-scale.

CHOOSING THE EF-SCALE

The aforementioned elements have made the EF-scale the most accurate in both its design and use for rating tornado intensities and matching realistic wind speeds to them.

Specifically, the choice of the EF-scale as a new reference scale for recording tornadoes in France by KERAUNOS since 2009 was broadly based on the following observations:

- *Only the EF-scale is a damages scale*, which makes it effective and practical for damage surveys. Its methodology is consistent with its use, unlike the F- and T-scales, which are wind speed scales, used incorrectly as damage scales.

- *Only the EF-scale offers calibrated wind speeds* designed by structural engineers, which is not the case with other F and T-scales.

- *Only the EF-scale offers a series of clearly defined damages indicators*. Conversely, the F-scale is essentially based on the "well-constructed frame home" to determine the degree of damage, which is an inaccurate choice and one poorly adapted to Europe.

- *Only the EF-scale enables the methodological and precise recording of past cases*. In fact, by definition, tornadoes of the past do not benefit from any wind speed measurements. The use of a wind scale (F- or T-scale) is therefore not suited to this context ; this is where analysis through damage (EF-scale) comes into its own, giving consistent and relevant analysis.

The EF-scale presents a multitude of advantages which have led KERAUNOS to choose this scale as a methodological reference. Specific studies were thereafter carried out, in order to capitalise on this new method of rating tornadoes in Europe; these studies are detailed below.

2 - ADAPTATION OF THE EF-SCALE TO A EUROPEAN CONTEXT

In order to be really relevant for use in Europe, the EF-scale requires some adjustments. A legitimate criticism would be that it includes a number of damage indicators which are dependent on American construction techniques and because of this it does not take into account the features of European housing (Doswell, 2009).

Although this remark is justified, the "Americanized" nature of certain damage indicators in the EF-scale should not be considered as an insurmountable obstacle. The EF-scale opens up many possibilities for adaptation to a European context, which simply need to be explored. This is exactly the goal of the studies which have been carried out since 2009 by the two authors of this study.

AN AUGMENTED EF-SCALE

Our study consisted firstly of compiling a list of all the damages caused by the 700 tornadoes listed in the KERAUNOS database for France, and by a certain number of tornadoes which occurred in other European countries. Thus, hundreds of European tornadoes were analysed in great detail, in order to determine for each one which type of building or vegetation was damaged and how.

This list was then compared to the 28 damage indicators already provided by the EF-scale. This first analysis showed that 18 damage indicators can be found in Europe, which shows that a non-negligible proportion of the EF-scale can already be applied in a European context. These 18 indicators can be qualified as *common*, since their features, although not always identical, are similar on both sides of the Atlantic. In this way, a level of determined damage would benefit from being recorded identically on the scale in the United States and in Europe.

These *common indicators* are as follows: 3, 6, 8, 11, 13, 14, 15, 16, 17, 18, 19, 21, 22,23, 25, 26, 27, 28. We will see later on that these *common indicators* are very useful because they allow to calibrate the EF-scale on the European continent. First on the list of these common indicators are indicators related to vegetation, which are the most universal of all and which need particular attention.

On the other hand, the other indicators which feature in the EF-scale can be considered as *specific*, as they are currently only used in the United States.

As we have just seen, if 18 damage indicators provided by the EF-scale can be applied in Europe, the fact remains that a certain number of typically European buildings do not benefit from any indicator: so what is to be done when a tornado hits a stone-built farmhouse? When the main damage concerns a church built from heavy stonework?

To solve this issue, KERAUNOS defined indicators specific to Europe, by drawing up its "augmented EF-scale". This adds all the elements necessary to the EF-scale in order for it to be applied to a European context.

21 NEW INDICATORS

To allow a good adaptation of the EF-scale to the European continent, 10 new damage indicators were drawn up in 2009, and presented publicly in 2011 as part of the 6th European Conference on Severe Storms (Mahieu, Wesolek, 2011). The work carried out since then by the two authors resulted in a more complete list of the definitive 21 damage indicators which were identified, defined and calibrated in order to adapt the EF-scale for Europe. The list of European indicators is shown below:

DI n°	DAMAGE INDICATOR (DI)	CODE
E-1	Small sheds, barns and other outbuildings	FBO
E-2	Small detached houses	COT
E-3	Detached houses	RHO
E-4	Multiple-storey terraced housing	UHO
E-5	Adjacent town buildings	UBO
E-6	Traditional farms	FAR
E-7	Windmills	MIL
E-8	Traditional factories and industrial buildings	FAC
E-9	Churches	CHU
E-10	Medieval castles	MECAS
E-11	Renaissance an dpost-Renaissance edifices	RECAS
E-12	Large commercial or recreational buildings	SMK
E-13	Electrical poles and pylons	PYL
E-14	Street lamps and lampposts	SLA
E-15	Fields, allotments, straw bales and greenhouses	AGR
E-16	Trees	TRE
E-17	Vines	VIG
E-18	Cemeteries	CEM
E-19	Motor vehicles	VEH
E-20	Caravans	CRV
E-21	Humans and animals	LIV

In addition, three other indicators are already defined, but not yet calibrated, due to the lack of a sufficiently large tornado panel. These indicators concern indeed very recent types of construction, which have been very rarely hit by tornadoes until now:

DI n°	DAMAGE INDICATOR (DI)
E-22	Contemporary houses and ecological housing
E-23	Contemporary multiple-storey residential housing
E-24	Aeolians

These indicators should enable intensity rating of most tornadoes occurring in Europe. It should be noted that some of these indicators can easily be used on other continents, in particular the "tree", "motor vehicles", "caravan" or even "human and animals" indicators.

NOTE ON INDICATORS

Environnement Canada conducted similar studies in Canada to those carried out by KERAUNOS in Europe. This led to the addition of 6 new indicators in 2013 for the Canadian territories (E.C., 2013):

DI n°	DAMAGE INDICATOR (DI)	CODE
C-1	Electrical transmission lines	C-ETL
C-2	Trees	C-T
C-3	Heritage churches	C-HC
C-4	Solid masonry houses	C-SMH
C-5	Farm silos or grain bins	C-FSGB
C-6	Sheds, fences or lawn furniture	C-SFLF

A total of 55 indicators have thus far been studied, calibrated and incorporated into the EF-scale (28 American, 6 Canadian and 21 European, detailed in this publication).

It should however be noted that at least two indicators are common to these various studies:

- we offer a "trees" indicator (E-16), which is already present in the American indicators 27 and 28 (Trees: hardwood; Trees: softwood), and in the Canadian indicator C-2 ("Trees"). Our approach does not contradict these other pre-existing indicators, but completes them with a more "dynamic" analysis that enables results to be specific in certain situations.

- our analyses and conclusions on the "church" indicator were the subject of communications between ourselves and Environnement Canada in 2013, who used it to create the Canadian indicator C-3 "Heritage churches"; it is therefore very close to the European indicator "churches" (E-9) featured in this publication.

METHODOLOGY

In accordance with the EF-scale, each new damage indicator has been analysed to determine its own degree of damage, from "minor damage" to "total destruction of the indicator". The link that was then established between each of these degrees of damage and the levels EF0 to EF5 was not random, but was determined according to an accurate and ordered methodology.

Our method consisted of *calibrating* each degree of damage for new European indicators by referencing damage experienced via a *common indicator* hit at the same time by the same tornado. In other words, the *common indicators* already listed in the EF-scale were used as a *standard* to determine the EF-scale levels associated with each degree of damage for the 21 new European indicators.

So, for example, it was possible to determine that tornadoes which cause EF2 damages on the HARDWOOD common indicator usually topple the spires of churches located near to these trees. Therefore, the "church spires toppled" degree of damage could be associated with an EF2 intensity.

In order to reach solid conclusions, these relationships were not established for a single event for each degree of damage, but over a multitude of cases studied comparatively: the calibration of new indicators is based on the *average of the most frequently observed correlations* between a degree of damage of an *indicator to be calibrated*, and a degree of damage *for a common indicator*. For example, it has been established that roofing tiles or sheets on E-2 type housing are torn off in 70% of cases of tornadoes which uproot trees; or similarly that 95% of cases of tornadoes which strip trees and deposit the leaves and branches some distance away also largely destroy E-3 type housing, or even push or project cars over short distances.

It is this *majority*, or in other words *predominant*, character of a relationship between two degrees of damage for two different indicators which gives the method used its reliability. This has the effect of neutralising any bias linked to unusual environmental configurations or sudden variations of tornado intensity, and only retaining correlations which are strongly representative and repetitive over a wide sample of cases.

This principle of calibration of new European indicators has been applied to over a thousand French and European tornadoes, in order to build a very broad spectrum of damages, which can cover a wide variety of intensities and configurations. A reliable and calibrated link between the degrees of damage for each indicator and an accurate tornado intensity rating was therefore established.

Naturally, given the limited frequency of violent tornadoes in Europe, some uncertainties remain concerning the exact damage caused by EF4 and EF5 tornadoes to certain indicators. Indeed, some adjustments to these levels could also be made in the future.

3 – LIST OF SPECIFIC DAMAGE INDICATORS FOR USE IN EUROPE

The 21 specific indicators drawn up by the authors for use in Europe are detailed below. Instructions for use are provided on page 16.

To ensure correct use of these tools, a certain number of remarks and preliminary advice is given below.

PRELIMINARY REMARKS

- It is important to keep in mind that each building or landscape element hit by a tornado reacts *in its own way*, depending on its strengths and its weaknesses, on the nearby environment which may partially protect it or conversely accentuate the damage, on the amounts of debris swept up by the tornado, etc. Faced with this complex reality, the damage indicators listed below attempt to identify *the generic categories of damages* and to provide for each of them a *reference intensity*, calibrated on a standard situation and a solid indicator. It is vital that the expertise on the ground qualifies this standard reference according to the aspects specific to each situation. To do this, high and low ranges are provided for each degree of damage, in order to supply a wide spectrum of references adapted to a wide variety of configurations.

- It is impossible to cover all varieties of construction found in Europe here. It is therefore recommended, when analysing damages on an unusual building which is not referenced, to base the analysis on the closest indicator category, then to determine its reliability in comparison to the typical indicator in order to use the intensity ranges properly.

- To analyse damage to buildings requires particular attention with regard to the condition and level of upkeep of the buildings. It is also important to take into account any specific features such as ties between roofs and walls, as well as between walls and foundations. Any structural weakness justifies the use of the low range. Conversely, any very strong structure in perfect condition justifies the use of the high range.

- Conventionally, tornado ratings are based on the maximum intensity, and not on the average intensity. In order to reliably determine this maximum intensity, it is recommended wherever possible, to compare several damage indicators close to one another in the zone where the most severe damages have been observed. In fact, an unusually high degree of damage on a single indicator can reveal unusual fragility in this indicator, and it is not necessarily the consequence of an intensification of the tornado. The comparative study of several indicators prevents any errors when drawing conclusions.

- Our knowledge of exact wind speeds generated by a tornado close to the ground remains uncertain. It is probable that estimated ranges provided to date in the EF-scale could be adjusted slightly in the future. There is debate regarding the lower end of the EF0 scale, which it is suggested could be adjusted to below the current threshold of 103 km/h, and some other debates are also ongoing concerning the wind speed associated with the highest

grades (EF4 and EF5). This is why the rankings given below are based *directly on EF gradings*, and not on absolute speeds, in order to compensate for these uncertainties.

- The analyses presented below and the wind speeds that may be associated with them in an estimative way are only valid for tornadoes. For a comparable wind speed, tornadoes produce damages which may vary depending on those caused by straight line winds. Therefore, the use of the EF-scale for analysing microbursts, macrobursts and other convective downbursts is not recommended.

- The conclusions presented below are not necessarily definitive. Some details may be adjusted in the future, in particular for the highest degrees of damage, for which the sample of tornadoes analysed is smaller due to their greater scarcity. Also it should be noted that the following indicators: "E-22 Contemporary homes and ecological housing", "E-23, Contemporary multiple-storey residential housing", and "E-24 Aeolians " are new indicators currently under study.

ADDITIONAL INFORMATION RELEVANT TO THIS STUDY

The studies carried out by the authors to adapt the EF-scale to the European context are based on hundreds of cases analysed over almost twenty years of damage surveys on all types of meteorological disasters. This has led us to:

- *Develop a dynamic approach*: as well as damage severity, the intensity of a tornado also manifests itself through the projections of objects/debris over a distance. For this reason, a dynamic analysis of damages is relevant in many circumstances, especially for tornadoes of moderate to violent intensity. The degrees of damage shown below therefore regularly suggest a dynamic approach (movement of objects, debris…), which completes a more static approach using the American and Canadian damage indicators.

- *Identify indicators even in a single sparsely populated zone*: work carried out by the authors has also attempted to provide accurate indicators in sparsely populated areas. In fact it is not unusual to find that a tornado concentrates its action in a strongly rural zone, where damage indicator data on housing is lacking. Particular attention has been paid to indicators relating to vegetation and crops, to provide an assessment of tornado intensity in all situations.

INSTRUCTIONS FOR USE

The sheets provided below for each indicator are all organised according to the same principle, detailed below:

E-9. CHURCHES [CHU]

damage indicator name and reference

DESCRIPTION OF INDICATOR

Solidly built parish churches (stone, brick, sandstone, granite) with vaulted nave, thick heavy stonework walls; roof consisting of slate, lead, copper or zinc; complex framework; bell tower(s) several dozen metres high.

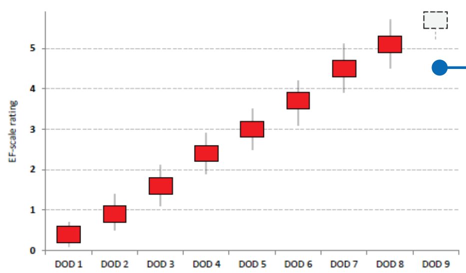
description of damage indicator features

DEGREE OF DAMAGE (DOD)

DOD	Damage description
1	first visible damage: decorative elements damaged
2	limited portions of roofing torn off (<20%)
3	significant loss of roofing (20-50%); slight damage to top of bell tower; some decorative elements in dressed stone broken or torn down (cross, gables, statues)
4	church spire toppled
5	major sections of roof torn off (50-80%), framework damaged; walls intact
6	more than 80% of roof torn off and carried over some distance; some walls collapsed; damage to bell tower structure
7	roof entirely torn off; many walls collapsed; bell tower partially destroyed
8	most of bell tower destroyed, most walls collapsed
9	total destruction of edifice

detailed description of degrees of damage (DOD), ranked from the weakest to the most severe, DOD 1 being the weakest degree of damage (DOD 0 = no damage)

POSITION OF DODS ON THE EF-SCALE



position of each of the degrees of damage on the EF-scale:
* the **standard position** is represented by a red rectangle
* the **low** and **high ranges are** represented by black vertical bars
* if the position is uncertain, the rectangle is grey, with dashes around its contours

NOTES

- churches built from bricks or light masonry: use the low range for all DODs
- small, very old, poorly maintained or damaged building with numerous weak points: the low range for all DODs
- very robust, large scale building (cathedrals): use the high range for all DODs

notes relating to the use of high and low ranges, as well as advice and instructions for using the indicator

EXAMPLES

Example of an E-9 indicator without damage (**DOD 0**):

selection of photographs (illustration of certain degrees of damage)

E-9 DOD 6 : Oostmalle tornado of June 25, 1967 (Malle, Belgium). Church of Oostmalle torn apart. © Heemkundige Kring van Malle, RTL Nieuws.

LIST OF DAMAGE INDICATORS FOR USE IN EUROPE

E-1.SMALL SHEDS, BARNS AND OTHER OUTBUILDINGS [FBO]

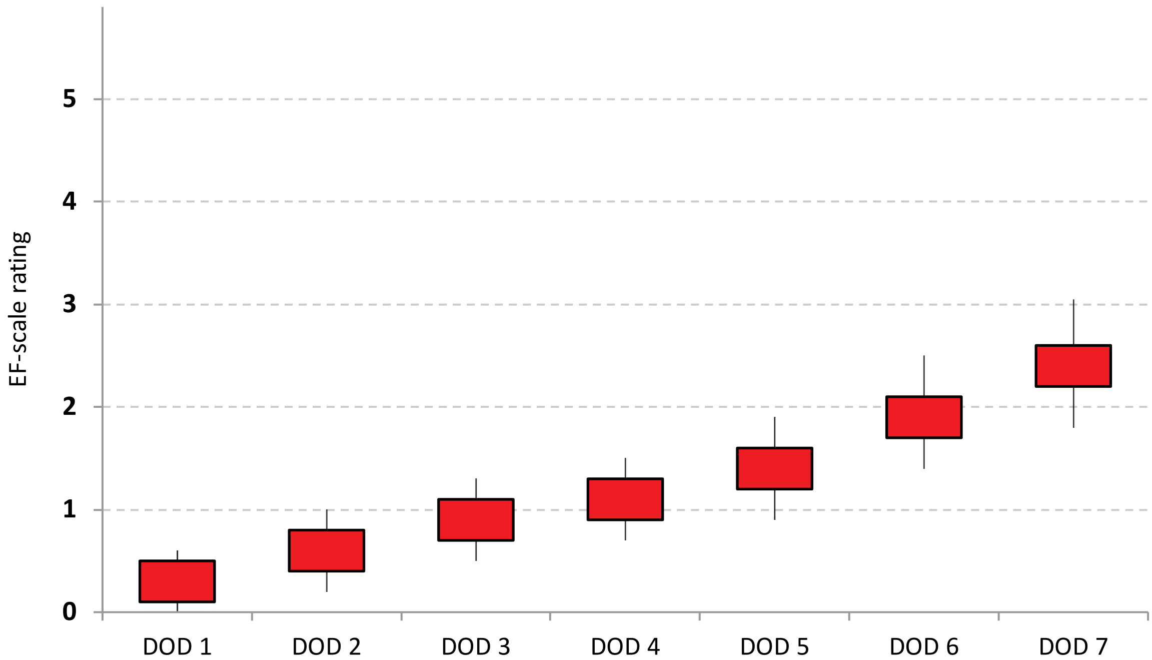
DESCRIPTION OF INDICATOR

Sheds, haylofts, stables and small sheds built from light masonry. Walls and partitions usually made from wood, breeze block or metal. Roofing generally made from metal sheeting, slates, or Plexiglas® or Everite® type sheeting. Mostly light materials used.

DEGREE OF DAMAGE (DOD)

DOD	Damage description
1	first visible damage: guttering and occasional roofing elements torn down, roofing sheets bent,...
2	less than 50% of roofing damaged or torn off, no distance projections or very minor cases
3	doors pushed in or torn off hinges
4	more than 50% of roofing damaged or torn off; a few distance projections
5	roofing entirely torn off, walls or partitions partially collapsed and/or collapsed structure with some projections in the distance
6	building almost entirely destroyed; building debris projected over moderate distance
7	building razed and blown away; building debris projected over a great distance

POSITION OF DODS ON THE EF-SCALE



NOTES

- very fragile, old, poorly maintained or damaged structures with numerous weak points: use the low range for all DODs
- openwork structures, with significant wind exposure and/or side openings: use the low range for all DODs
- larger structures or those with a certain level of robustness: use the high range for all DODs

EXAMPLES

Example of an **E-1** indicator without damage (**DOD 0**):

E-1 DOD 7 : Humbert tornado of August 23, 2010 (France). Shed blown away, and debris projected over distance. © P. Mahieu, E. Wesolek / KERAUNOS.

E-2. SMALL DETACHED HOUSES [COT]

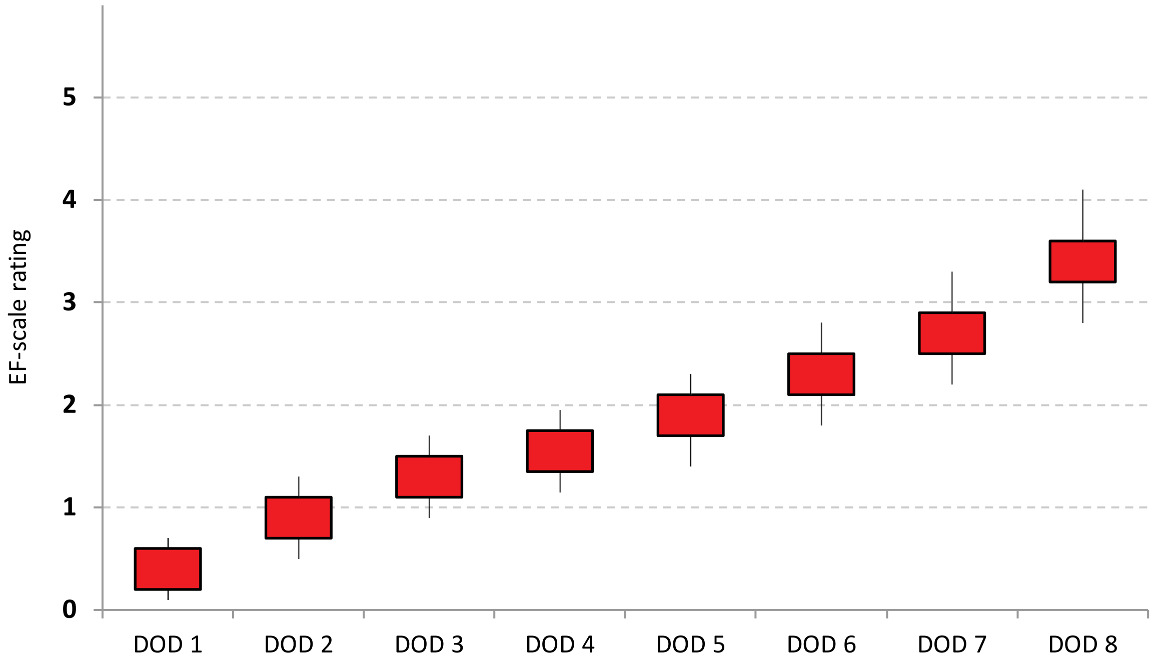
DESCRIPTION OF INDICATOR

Small housing, such as cottages, with the following common features: exterior walls generally made from cob or light masonry, non-existent or few interior walls, a few partitions. Wooden roofing structure, thatched, slate or tiled roof. Very typical of older rural housing.

DEGREE OF DAMAGE (DOD)

DOD	Damage description
1	first visible damage, superficial roof damage
2	between 10 and 50% of roofing damaged
3	more than 50% of roofing blown away
4	roofing totally blown away but roof structure intact
5	roofing torn off, roof structure damaged
6	roof blown away (roof structure blown away), walls damaged
7	housing partially destroyed, many walls collapsed
8	housing totally destroyed

POSITION OF DODS ON THE EF-SCALE



NOTES

- very fragile, old, poorly maintained or damaged structures with numerous weak points: use the <u>low range</u> for all DODs
- relatively robust houses and/or in excellent condition: use the <u>high range</u> for all DODs

EXEMPLES

Example of an **E-2** indicator without damage (**DOD 0**):

E-2 DOD 8 : Dreux tornado of August 18, 1890 (France). House destroyed in the Saint-Thibault neighborhood. © Keraunos archives.

E-3. DETACHED HOUSES [RHO]

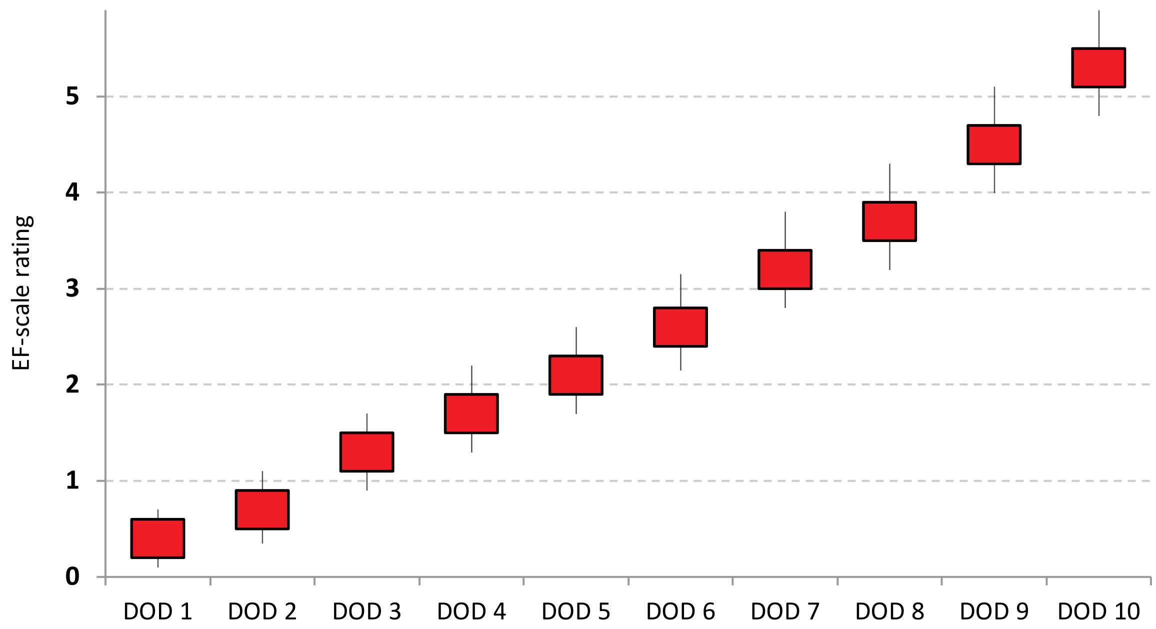
DESCRIPTION OF INDICATOR

Detached houses built from masonry, contemporary or traditional, with two levels and/or a pitched roof. Exterior and interior walls, multiple dividing walls, light or heavy masonry, roof sometimes with complex structure. Typically detached suburban housing.

DEGREE OF DAMAGE (DOD)

DOD	Damage description
1	first visible damage: some tiles moved, TV aerial twisted
2	roofing damaged (<20%), guttering and/or ridge tiles torn off
3	windows broken (windows or glazed doors), roofing partially torn off (20 to 50%),
4	more than 50% of roofing torn off, chimney stacks collapsed, garage doors bent inwards, ceilings raised, double-glazed patio doors sometimes smashed
5	roofing mostly torn off (>80%), large portions of roofing framework torn down, walls intact
6	roof entirely torn off and exterior walls damaged or collapsed
7	first floor partially or totally destroyed (interior or exterior walls destroyed), bungalows torn apart
8	exterior ground-floor walls demolished, only interior walls left standing
9	building totally destroyed
10	building razed and blown away, possible damage even at basement level

POSITION OF DODS ON THE EF-SCALE



NOTES

- very fragile, old, poorly maintained or damaged structures with numerous weak points: use the <u>low range</u> for all DODs
- very robust houses in good state of repair: use the <u>high range</u> for all DODs
- houses with some concrete walls: use the <u>high range</u> for all DODs
- Houses with concrete structure: do not use this indicator

EXAMPLES

Example of an **E-3** indicator without damage (**DOD 0**):

E-3 DOD 9 : Hautmont tornado of August 3, 2008 (France). House almost totally destroyed in Boussières-sur-Sambre. © P. Mahieu, E. Wesolek / KERAUNOS.

E-4. MULTIPLE-STOREY TERRACED HOUSING [UHO]

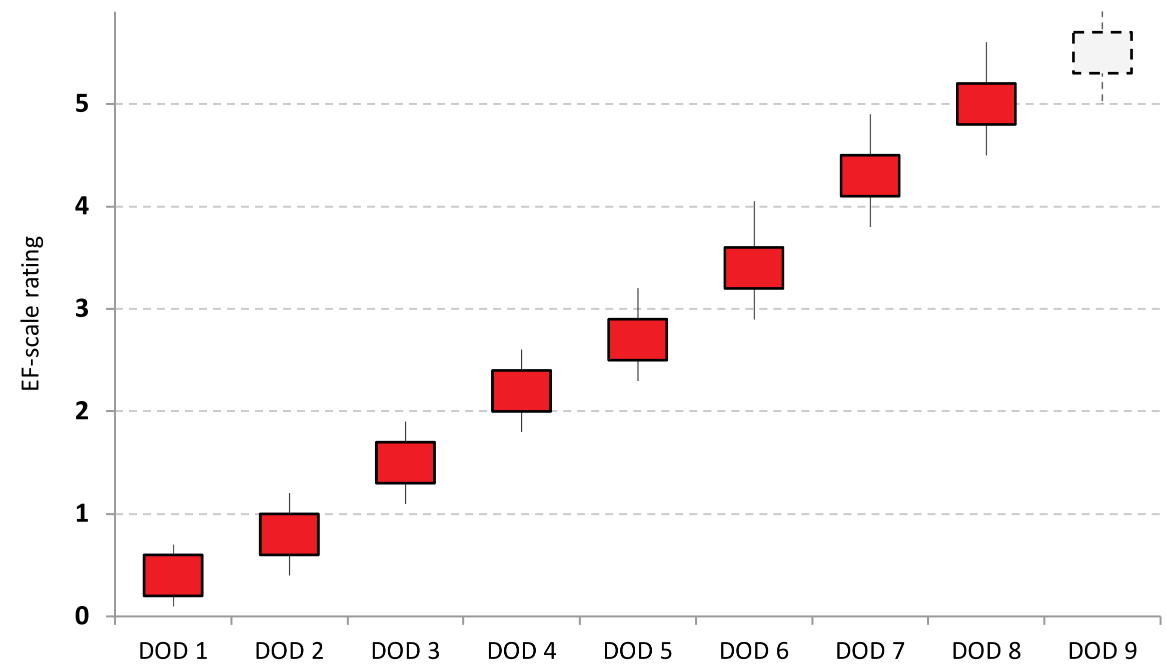
DESCRIPTION OF INDICATOR

Housing complexes, masonry built; houses found particularly in the historical centres of towns and villages, in town outskirts, hamlets or terraced workers housing. Houses with one or more floors, shared walls, pitched roof, light or heavy masonry, and timber frame roofing structure.

DEGREE OF DAMAGE (DOD)

DOD	Damage description
1	first visible damage: TV aerials bent, ridge tiles damaged, guttering displaced, twisted or torn off, gables damaged
2	roofing slightly damaged (<20%)
3	roofing damaged (20 to 50%)
4	most of roofing torn off (> 50%), roofing framework damaged
5	roof entirely torn off or collapsed, upper floor walls damaged
6	house torn apart, upper floor destroyed, ground floor intact
7	most of building destroyed, ground floor walls partially collapsed
8	building entirely destroyed
9	building razed and blown away, possible damage even at basement level

POSITION OF DODS ON THE EF-SCALE



NOTES

- very fragile, old, poorly maintained or damaged structures with numerous weak points: use the <u>low range</u> for all DODs
- very robust houses in good state of repair: use the <u>high range</u> for all DODs
- houses with concrete walls: use the <u>high range</u> for all DODs

EXAMPLES

Example of an **E-4** indicator without damage (**DOD 0**):

E-4 DOD 6 : Tricht tornado of June 25, 1967 (Netherlands). Upper floor of a housing complex destroyed. © Dutch National Archives.

E-5. ADJACENT TOWN BUILDINGS [UBO]

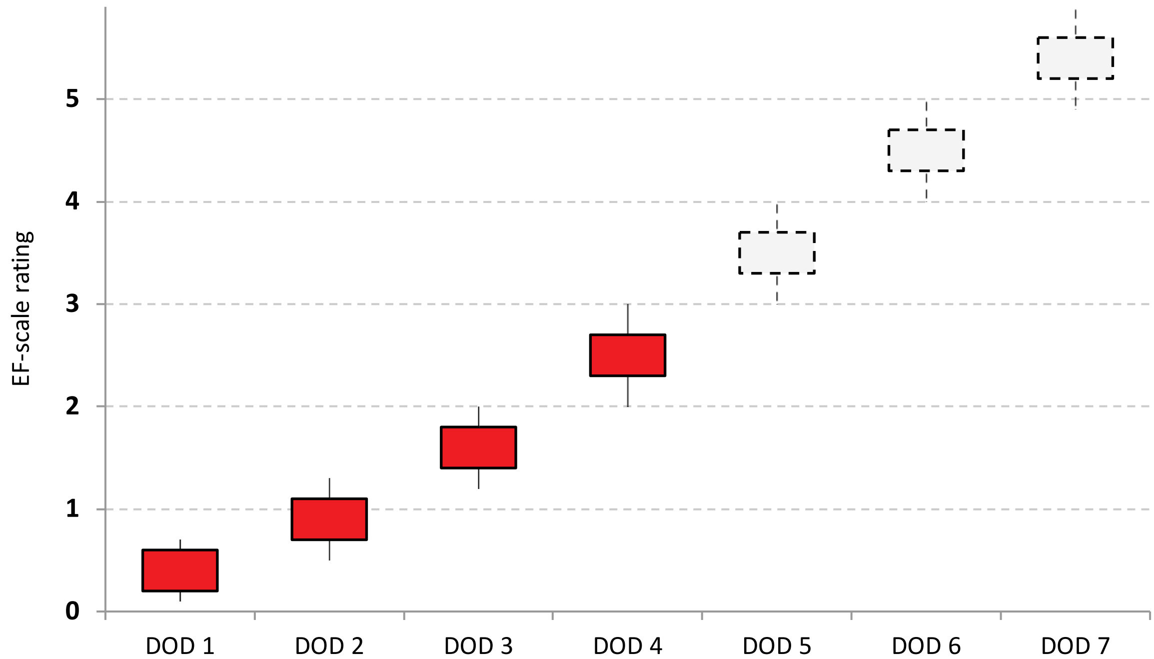
DESCRIPTION OF INDICATOR

Town houses main built from stone or brick, in terraces, built to the same height and design in wide avenues and boulevards from the 18th century and throughout the 19th century. Multi-storey buildings (most often between three and five floors) with pitch roof, lead, zinc or copper roofing, large chimney stacks and sometimes several decorative or aesthetic elements (gables, statues, balconies, pilasters).

DEGREE OF DAMAGE (DOD)

DOD	Damage description
1	first visible damage: ridge tiles damaged, guttering displaced, twisted or torn off, gables damaged
2	roofing elements bent or folded, some roofing elements torn away (<20%)
3	roofing torn off (20 to 50%), large chimney stacks and gables collapsed
4	more than 50% of roofing torn off, some framework torn away
5	roof torn off, upper floors partially collapsed, multiple damage to all upper floors
6	upper floor destroyed, structural damage to whole building
7	upper floors destroyed, significant structural damage to entire building

POSITION OF DODS ON THE EF-SCALE



NOTES

- fragile, old, poorly maintained or damaged structures with numerous weak points: use the low range for all DODs
- very robust houses in good state of repair: use the high range for all DODs
- this indicator has not yet been evaluated for concrete houses: do not use in this case

EXAMPLES

Example of an **E-5** indicator without damage (**DOD 0**):

E-6. TRADITIONAL FARMS [FAR]

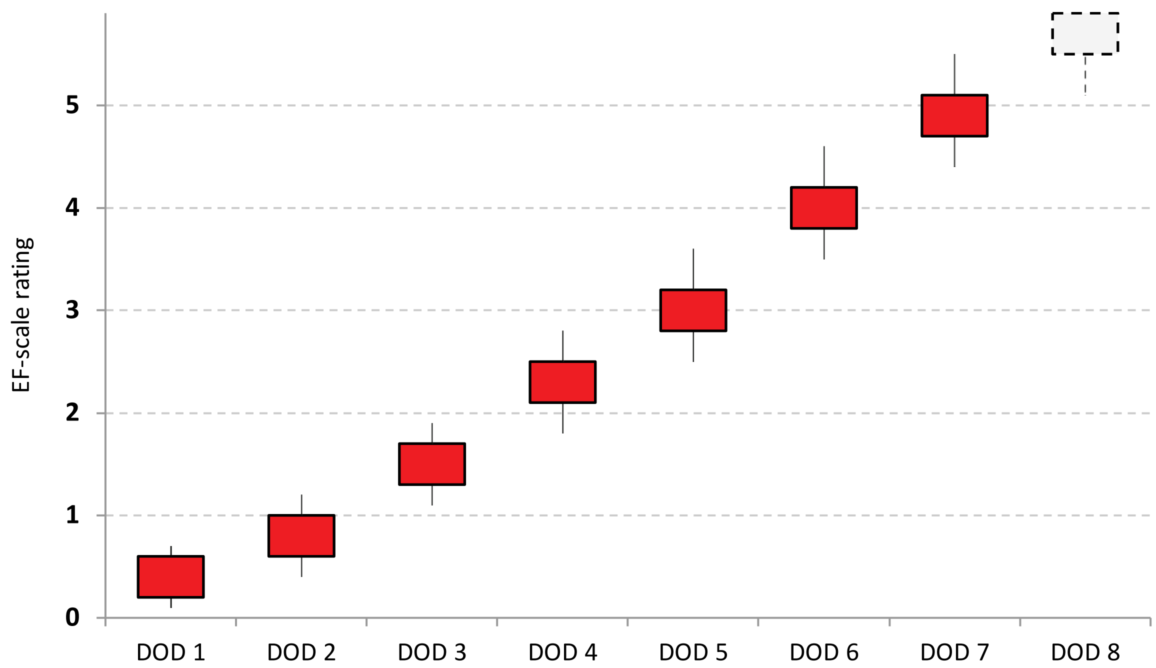
DESCRIPTION OF INDICATOR

Farms or masonry-built dwellings (dressed stone, brick, sandstone, granite) with heavy masonry; thick, strong walls, roof with complex structure, slate or tile roofing; pitch roof.

DEGREE OF DAMAGE (DOD)

DOD	Damage description
1	superficial damage: ridge tiles damaged, guttering displaced, twisted or torn off
2	a few tiles moved (< 20% of the total roof)
3	20 to 50% of the roofing destroyed, roof framework intact
4	majority of roofing blown away (>50%) with some roof framework torn down, walls intact
5	roof entirely blown off, exterior walls partially damaged
6	many walls seriously damaged or collapsed
7	very few sections of walls remain standing
8	building entirely destroyed from the floors up

POSITION OF DODS ON THE EF-SCALE



NOTES

- fragile, old, poorly maintained or damaged structures with numerous weak points: use the <u>low range</u> for all DODs
- very robust houses in good state of repair: use the <u>high range</u> for all DODs
- timber framed farmhouses: use indicator E-2 "small detached houses"

EXAMPLES

Example of an **E-6** indicator without damage (**DOD 0**):

E-6 DOD 5 : La Ferrière tornado of June 12, 1926 (Swiss). Roof of a farm completely torn off in La Chaux-de-Fonds; exterior walls partially damaged. © Library of La Chaux-de-Fonds.

E-7. WINDMILLS [MIL]

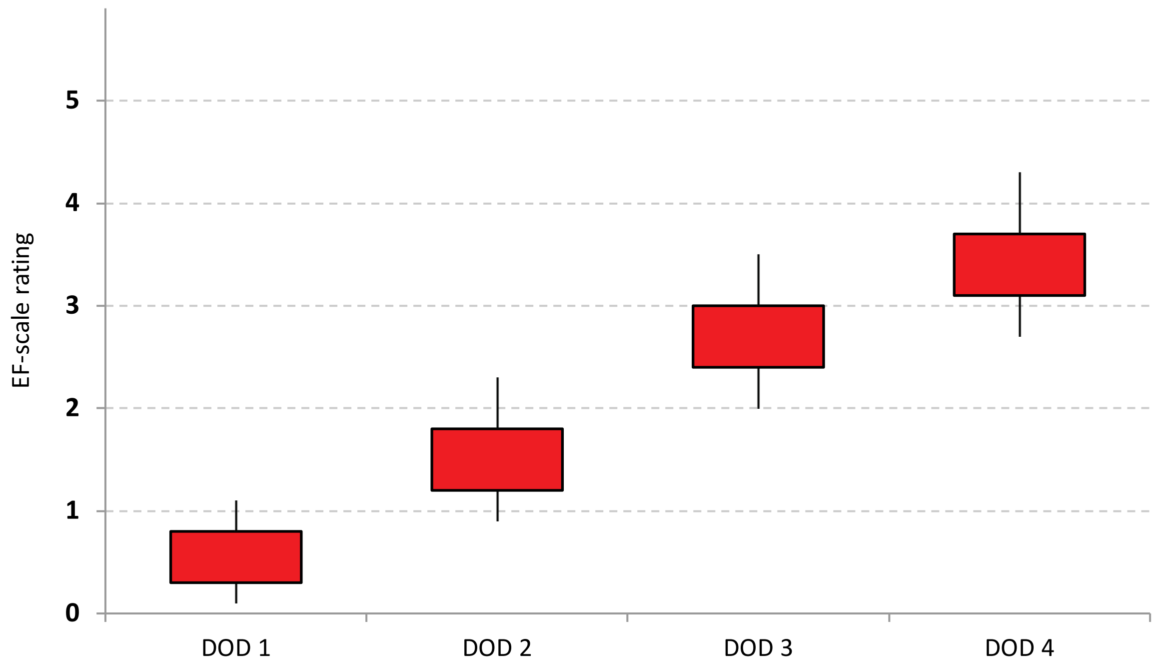
DESCRIPTION OF INDICATOR

Traditional windmills: masonry load-bearing structure (tower mill), or entire corpus built from timber (fulcrum mill), or mixed structures (horizontal mill, smock mill). Common features: removable dome, timber framed roof and blades.

DEGREE OF DAMAGE (DOD)

DOD	Damage description
1	superficial damage: some parts of roof blown off
2	dome or top section of fulcrum windmills blown off
3	structure partially destroyed, some timbers torn off and partial resistance of masonry-built sections
4	structure entirely destroyed

POSITION OF DODS ON THE EF-SCALE



NOTES

- fulcrum windmill: use the <u>low range</u> for all DODs
- tower windmill: use the <u>high range</u> for all DODs

EXAMPLES

Example of an **E-7** indicator without damage (**DOD 0**):

E-7 DOD 2 : Zaandam tornado of August 21, 1930 (Netherlands). Dome of the windmill of Zaansche blown off. © Dutch National Archives.

E-8. TRADITIONAL FACTORIES AND INDUSTRIAL BUILDINGS [FAC]

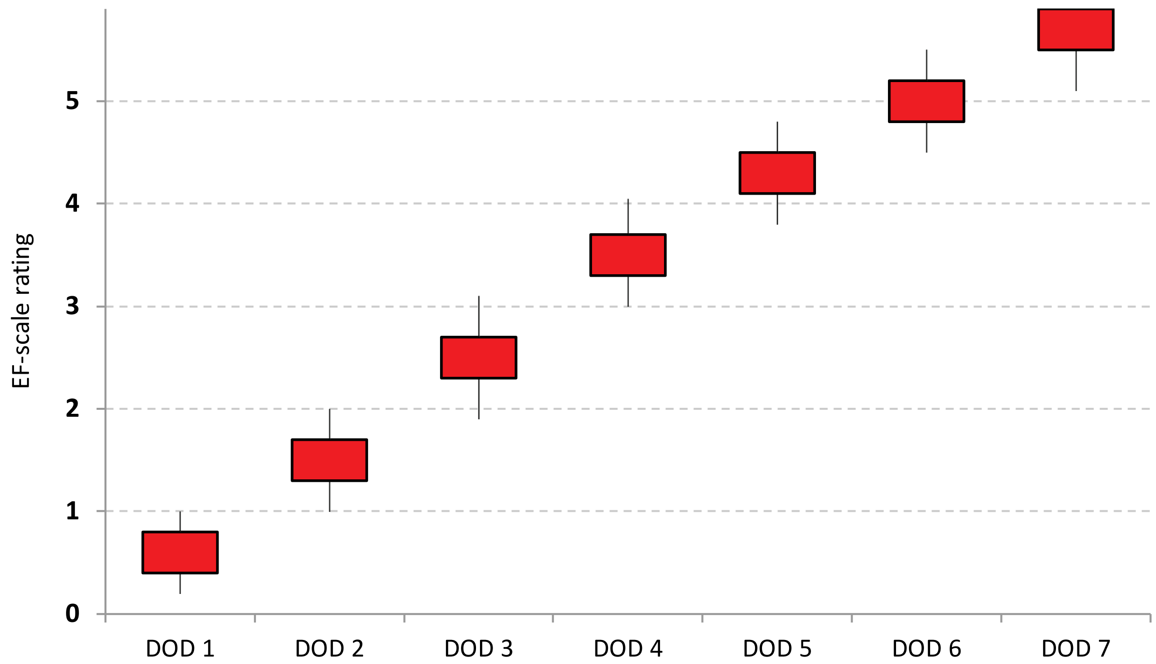
DESCRIPTION OF INDICATOR

Vast brick-built structures (spinning mills, cloth mills, flour mills,…), with large interior spaces. Multi-storey constructions (between three and six storeys) and generally flat-roofed, rarely pitch roofed. Buildings often featuring large brick chimney stacks several dozen metres high.

DEGREE OF DAMAGE (DOD)

DOD	Damage description
1	superficial damage: some roofing elements torn off (gutters, embellishments)
2	light damage to roofing or upper floors: roofing and waterproofing elements torn off, windows broken; small portions of roofing torn off (< 20%); chimneys collapsed
3	significant portion of roofing torn down (20 to 50%); chimneys collapsed or mostly destroyed
4	more than 50% of roof torn down, with partial destruction of upper floors (ceilings, walls of upper floors)
5	roofing totally torn off, many walls collapsed on upper floors, building torn apart
6	building largely destroyed, many walls collapsed on lower floors
7	building entirely destroyed

POSITION OF DODS ON THE EF-SCALE



NOTES

- fragile, very old, poorly maintained or damaged structures with numerous weak points: use the low range for all DODs

- very robust building in good state of repair: use the high range for all DODs

- building with concrete structure: do not use this indicator

EXAMPLES

Example of an **E-8** indicator without damage (**DOD 0**):

E-8 DOD 5 : Neede tornado of June 1st, 1927 (Netherlands). One of the main buildings of the Ter Weeme & Fils factory torn apart. © Dutch National Archives.

E-8 DOD 5 : Wiener Neustadt tornado of July 10, 1916 (Austria). Building of a locomotive factory torn apart. © www.schlot.at.

E-9. CHURCHES [CHU]

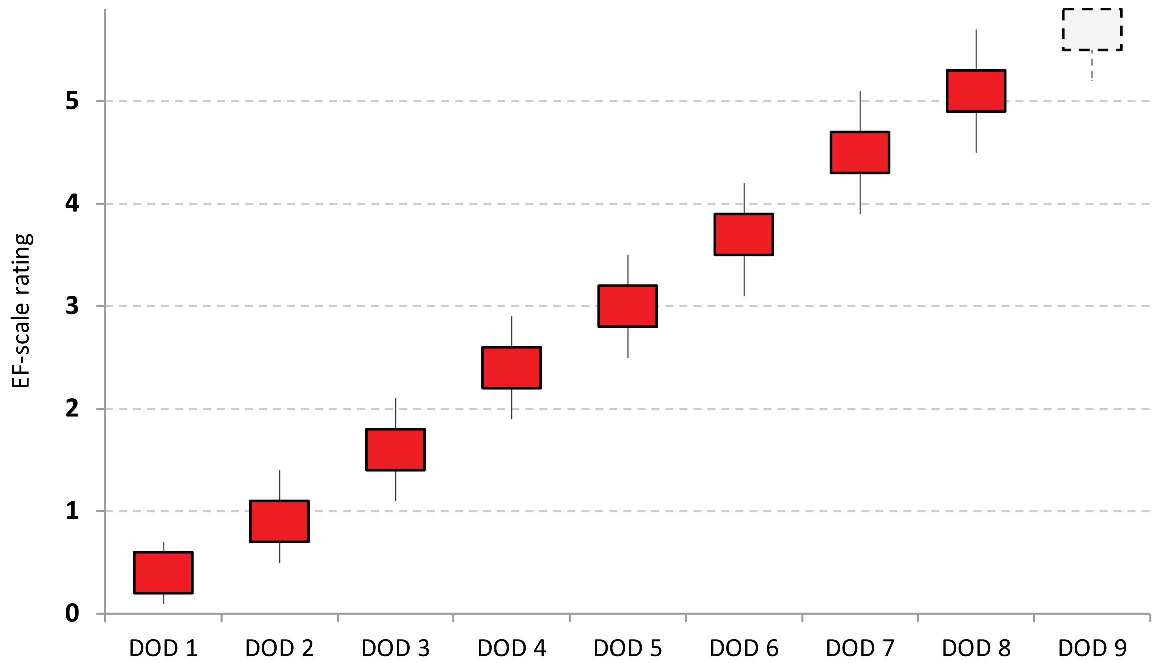
DESCRIPTION OF INDICATOR

Solidly built parish churches (stone, brick, sandstone, granite) with vaulted nave, thick, heavy stonework walls; roof consisting of slate, lead, copper or zinc; complex framework; bell tower(s) several dozen metres high.

DEGREE OF DAMAGE (DOD)

DOD	Damage description
1	first visible damage: decorative elements damaged
2	limited portions of roofing torn off (<20%)
3	significant loss of roofing (20-50%); slight damage to top of bell tower; some decorative elements in dressed stone broken or torn down (cross, gables, statues)
4	church spire toppled
5	major sections of roof torn off (50-80%), framework damaged; walls intact
6	more than 80% of roof torn off and carried over some distance; some walls collapsed; damage to bell tower structure
7	roof entirely torn off; many walls collapsed; bell tower partially destroyed
8	most of bell tower destroyed, most walls collapsed
9	total destruction of edifice

POSITION OF DODS ON THE EF-SCALE



NOTES

- churches built from bricks or light masonry: use the low range for all DODs
- small, very old, poorly maintained or damaged building with numerous weak points: use the low range for all DODs
- very robust, large scale building (cathedrals): use the high range for all DODs

EXAMPLES

Example of an **E-9** indicator without damage (**DOD 0**):

E-9 DOD 6 : Oostmalle tornado of June 25, 1967 (Malle, Belgium). Church of Oostmalle torn apart. © Heemkundige Kring van Malle, RTL Nieuws.

E-9 DOD 8 : Montello tornado of July 24, 1930 (Italy). Church of Selva del Montello almost completely destroyed. © Keraunos archives.

E-10. MEDIEVAL CASTLES [MECAS]

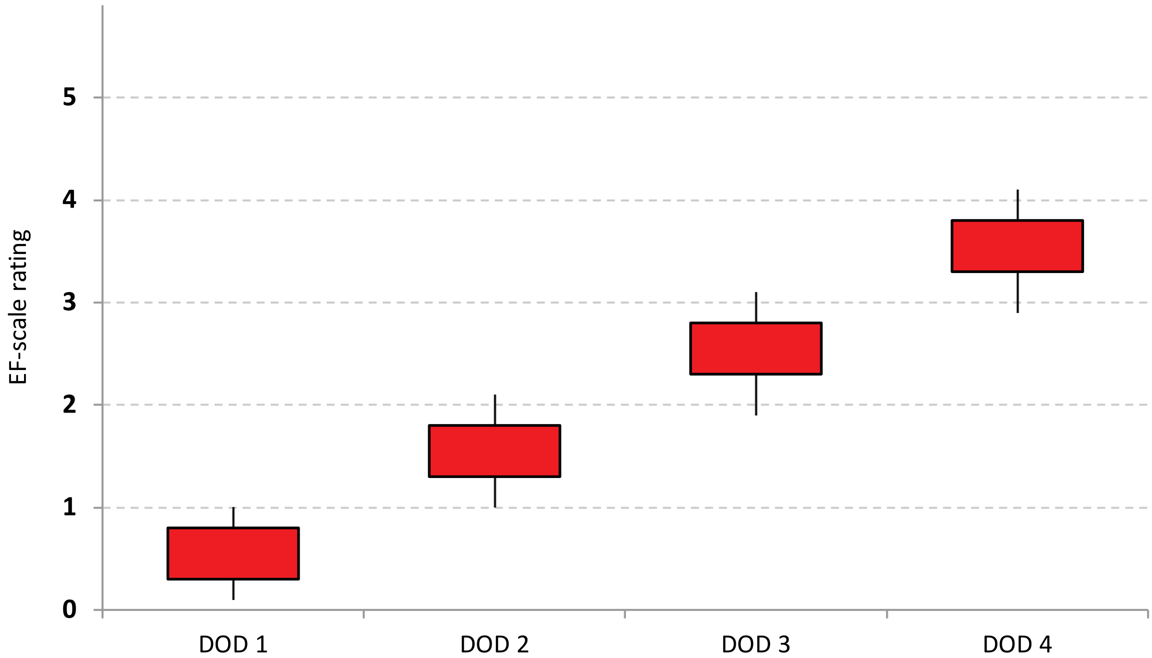
DESCRIPTION OF INDICATOR

Castles or fortresses featuring very thick walls in heavy stonework, few windows and few decorative elements. Towers, dwellings and keeps with roofing and roof framework.

DEGREE OF DAMAGE (DOD)

DOD	Damage description
1	minor roofing damage: less than 20% of roofing damaged
2	between 20 and 50% of roofing damaged, falling stonework and broken windows, building structure intact
3	roofing heavily damaged (> 50%), some damage to framework, possible structural damage to upper levels
4	upper levels damaged: ceilings and dividing walls collapsed, walls cracked, roofs entirely torn off

POSITION OF DODS ON THE EF-SCALE



NOTES

- damage above DOD 4 has not been observed to date; the indicator cannot therefore be informed until a building has been totally destroyed
- small, very old, poorly maintained or damaged building with numerous weak points: use the <u>low range</u> for all DODs
- very robust, large scale building: use the <u>high range</u> for all DODs

EXAMPLES

Example of an **E-10** indicator without damage (**DOD 0**):

E-11. RENAISSANCE AND POST-RENAISSANCE EDIFICES [RECAS]

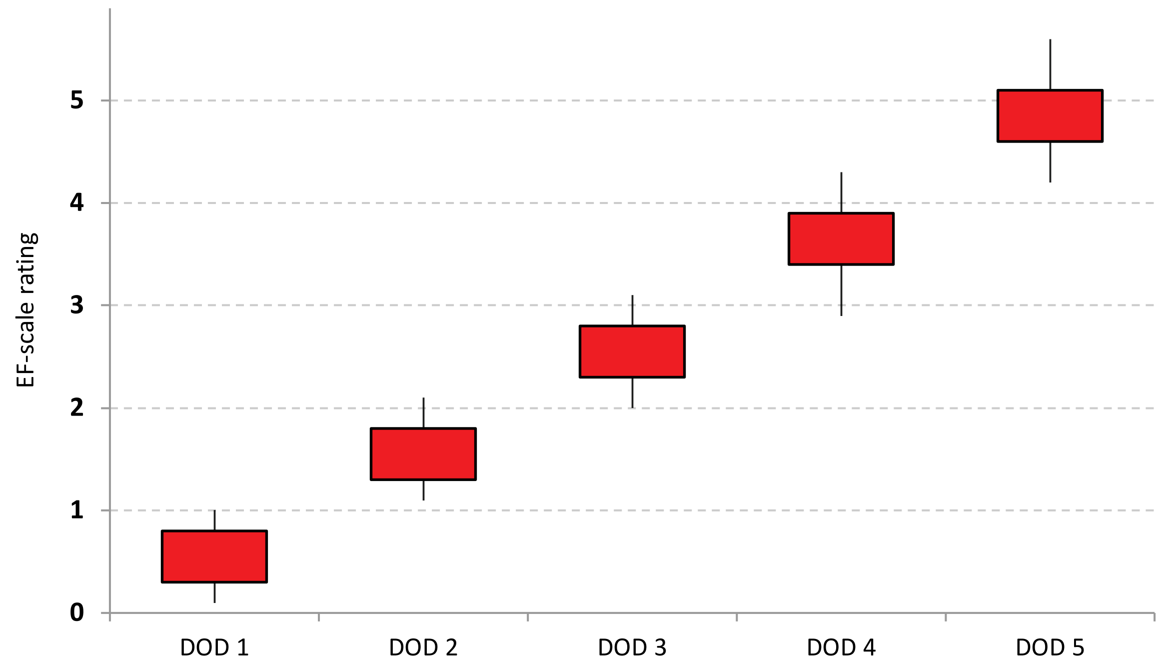
DESCRIPTION OF INDICATOR

Vast constructions (castles, manors, palaces) located in urban or rural environments, built after the Renaissance and up to the beginning of the 20th century: slender, with openwork, many large doors and windows, richly decorated, with towers, gables, pinnacle turrets. Large scale civic monuments, built from noble materials (brick, stone), thick walls, robust and pitch roofs: town halls, courthouses, old hospitals or hospices.

DEGREE OF DAMAGE (DOD)

DOD	Damage description
1	minor damage, some roofing elements torn down (< 20%), decorative elements sometimes destroyed or torn down
2	roof damaged (20 to 50%) but framework intact, chimneys collapsed, windows broken, numerous decorative elements and gables damaged
3	roof largely torn off (> 50%), roof timbers damaged, some exterior walls cracked
4	roof torn off, exterior walls cracked, upper floors damaged or torn apart
5	building largely destroyed, some sections of wall remain standing on ground floor

POSITION OF DODS ON THE EF-SCALE



NOTES

- damage above DOD 5 has not been observed to date; the indicator cannot therefore be informed until a building has been totally destroyed with the whole structure blown away
- small, very old, poorly maintained or damaged building with numerous weak points: use the <u>low range</u> for all DODs
- very robust, large scale building: use the <u>high range</u> for all DODs

EXAMPLES

E-11 without damage (**DOD 0**) and **E-11 DOD 5** : Mira tornado of July 8, 2015 (Italy). Almost total destruction of the Villa Fini (17th century) in Dolo.

E-12. LARGE COMMERCIAL OR RECREATIONAL BUILDINGS [SMK]

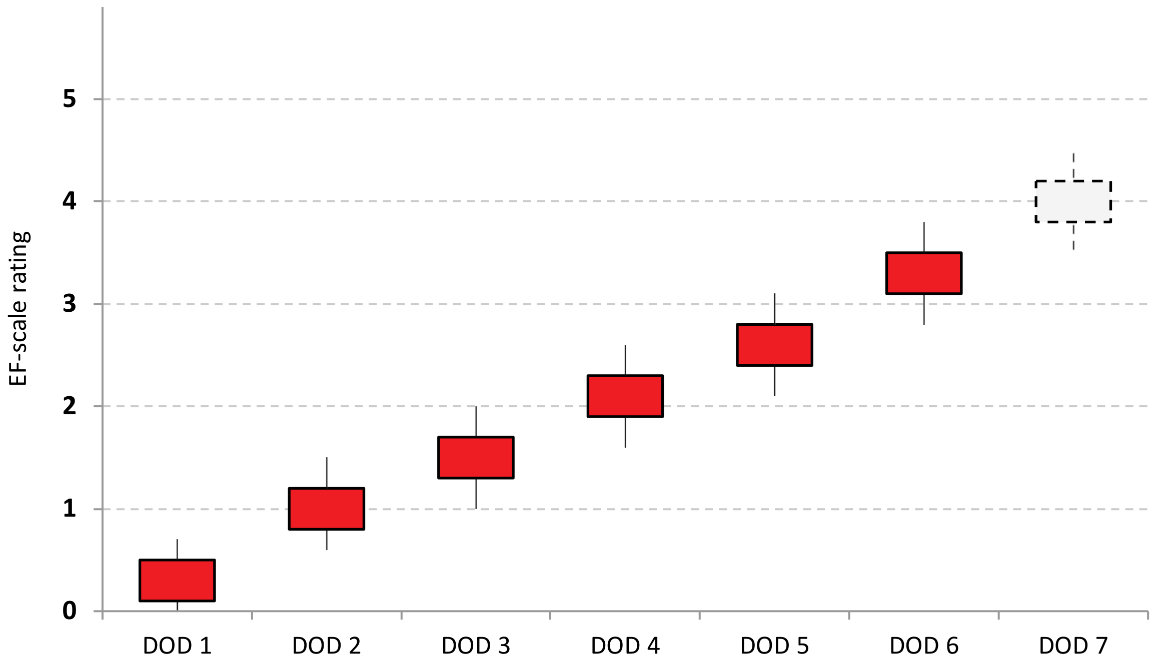
DESCRIPTION OF INDICATOR

Buildings with large surface area, flat roof, rarely multi-storey, usually occupied by supermarkets, specialised stores or gymnasiums, and built in industrial and commercial zones. Structure most commonly made from metal framework, with small sections of masonry, with exterior walls made from wooden panels, metal or concrete, with cladding and glass walls.

DEGREE OF DAMAGE (DOD)

DOD	Damage description
1	first visible damage: some pieces of cladding torn off
2	roof covering blown off (<20%)
3	significant losses to roofing elements (20 to 50%), store windows often broken
4	most of the roof structure torn off (> 50%)
5	roof entirely torn apart and part of walls collapsed
6	building largely destroyed, many walls collapsed
7	building entirely destroyed

POSITION OF DODS ON THE EF-SCALE



NOTES

- this indicator does not benefit from a very broad study sample; it may be subject to adjustments in the future
- small, old, poorly maintained or damaged building with numerous weak points: use the <u>low range</u> for all DODs
- very robust, large scale building: use the <u>high range</u> for all DODs

EXAMPLES

Example of an **E-12** indicator without damage (**DOD 0**):

E-12 DOD 3 : Les Pennes-Mirabeau tornado of October 14, 2012 (France). Significant losses to roofing elements. © D. Dumas / KERAUNOS.

E-13. ELECTRICAL POLES AND PYLONS [PYL]

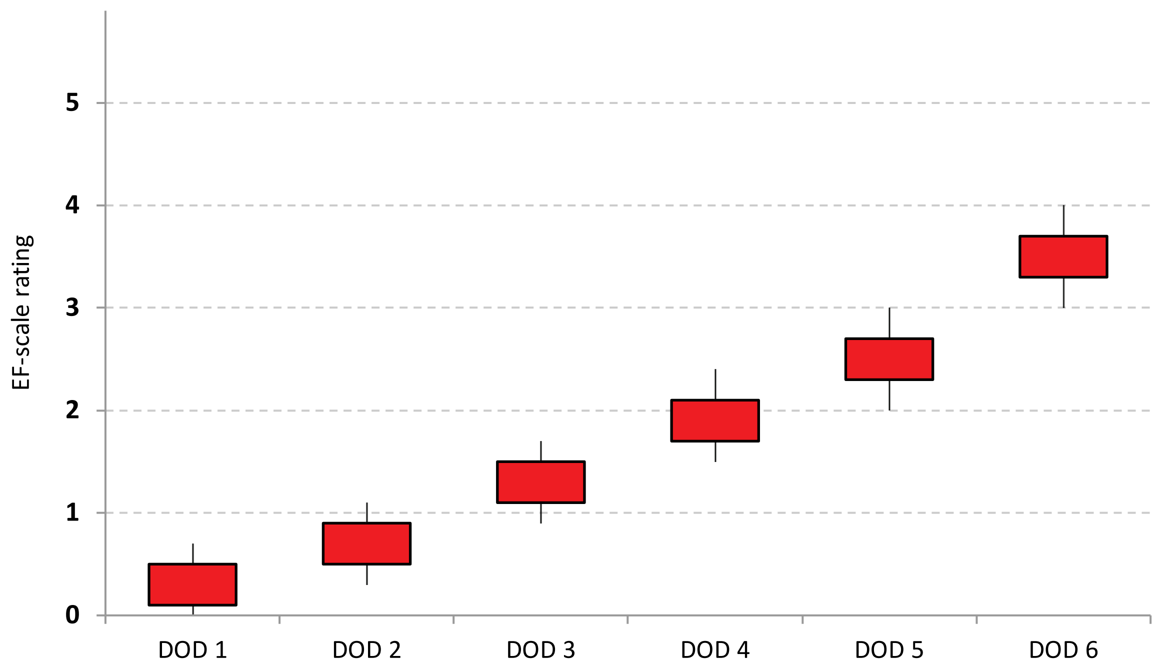
DESCRIPTION OF INDICATOR

Low, medium and high voltage electricity poles or pylons.

DEGREE OF DAMAGE (DOD)

DOD	Damage description
1	first visible damage (small debris hanging from cables)
2	low voltage transmission poles (wooden) broken, electrical cables grounded
3	timber electricity poles leaning or levelled
4	timber electricity poles snapped
5	metal or concrete electricity poles leaning or twisted
6	high voltage pylons toppled; concrete pylons snapped

POSITION OF DODS ON THE EF-SCALE



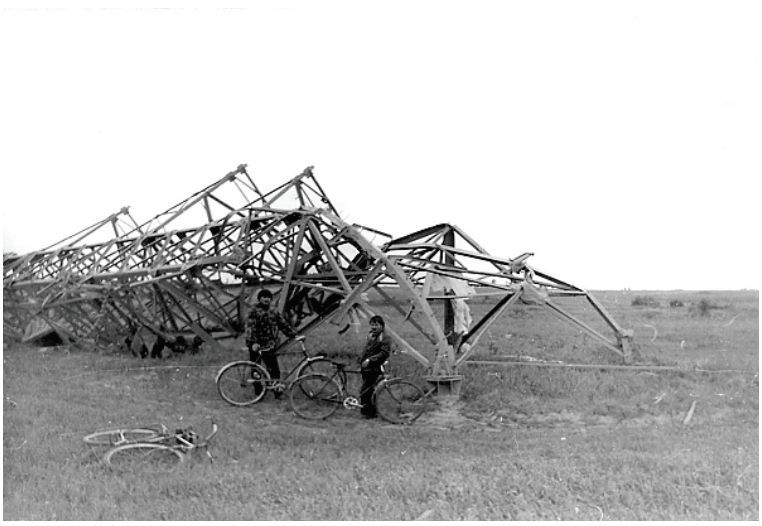
NOTES

- poorly maintained or damaged pole or pylon: use the <u>low range</u> for all DODs
- recent and very robust pole or pylon: use the <u>high range</u> for all DODs

EXAMPLES

Example of an **E-13** indicator without damage (**DOD 0**):

E-13 DOD 6 : Ivanovo tornado of June 6, 1984 (Russia). High voltage pylons toppled.



E-14. STREET LAMPS AND LAMPPOSTS [SLA]

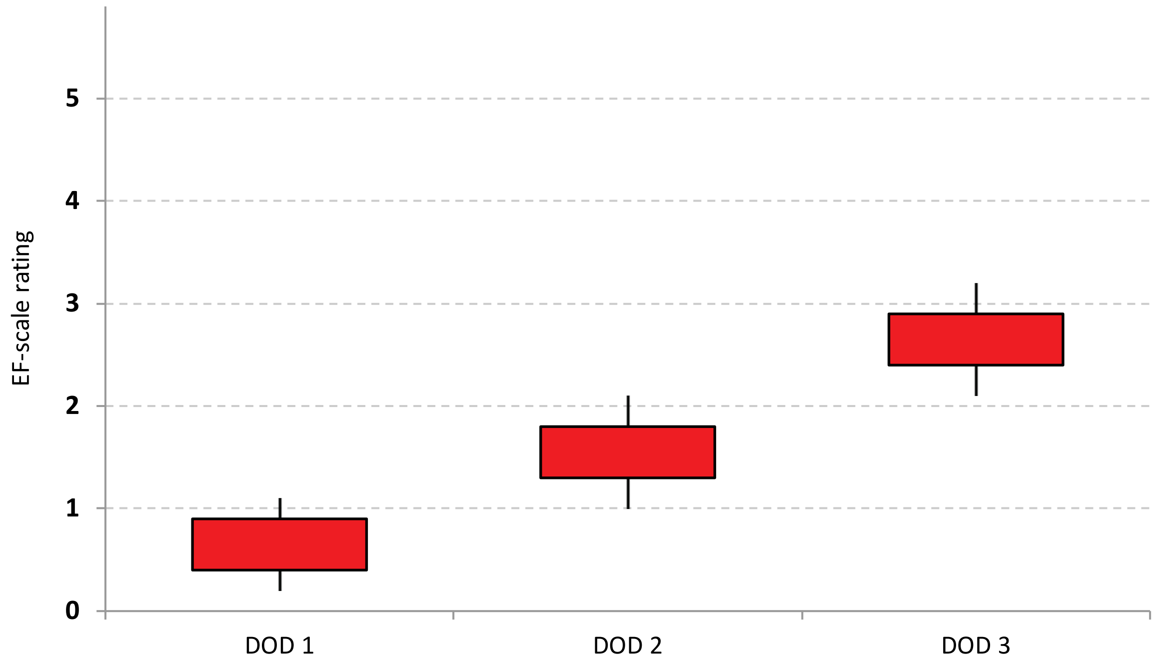
DESCRIPTION OF INDICATOR

Street lamps and lampposts with shaft, stick and single or multiple lights.

DEGREE OF DAMAGE (DOD)

DOD	Damage description
1	first visible damage: light damaged or broken
2	street lamp or lamppost leaned over
3	street lamp or lamppost twisted, broken or ripped out

POSITION OF DODS ON THE EF-SCALE



NOTES

- poorly maintained or damaged street lamp or lamppost: use the <u>low range</u> for all DODs
- robust street lamp or lamppost: use the <u>high range</u> for all DODs

EXAMPLES

Example of an **E-14** indicator without damage (**DOD 0**):

E-15. FIELDS, ALLOTMENTS, STRAW BALES AND GREENHOUSES [AGR]

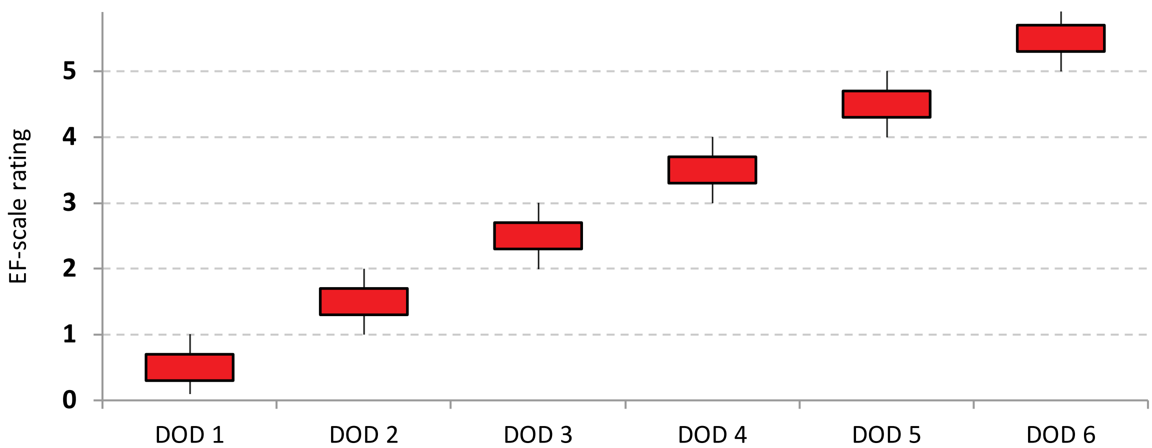
DESCRIPTION OF INDICATOR

Features of agricultural landscape: crops, gardens, fields, straw bales, greenhouses and vegetable plots.

DEGREE OF DAMAGE (DOD)

DOD	Damage description
1	low vegetation (flowering and fruiting plants) damaged or crushed; greenhouses with hoops and sheeting very damaged or mostly destroyed; structure intact but glass panes broken on greenhouses built from durable materials (frame solidly anchored in the ground, glass coverings); garden furniture sometimes overturned; garden shed roofs (wooden chalet type) sometimes blown off; corn rows slightly flattened or tangled together along the tornado's trajectory; sheaves dispersed, straw or hay scattered
2	solidly built greenhouses raised off the ground, with main structure bent or partially destroyed and covering mostly destroyed; garden furniture carried by winds over some distance; garden shed roofs (wooden chalet type) blown off; or shed totally destroyed; most corn rows flattened along the tornado's trajectory, with sheaves blown short distances away, straw or hay scattered; straw bales (roundballers of 300 to 500 kg) moved or overturned, sometimes rolling considerable distances
3	total destruction of solidly built greenhouses with debris scattered over long distances; corn rows totally flattened along the tornado's trajectory with the formation of a trench and sheaves blown considerable distances; straw bales moved, raised off the ground and carried away over some distance
4	corn rows partially torn up, with sheaves or entire plants blown some distance; rape plants totally destroyed or reduced to stumps; straw bales carried away over some distance and dispersed
5	corn rows mostly torn out, especially when tornado carrying a heavy load of debris within its vortex, with sheaves carried sometimes several kilometres away
6	corn fields stripped back to the soil, leaving only roots; grass torn from soil

POSITION OF DODS ON THE EF-SCALE



NOTES

- the use of wheat in this indicator is now not considered relevant, given its often unpredictable reaction in the face of a tornado.

- some tornadoes have only limited contact with the ground (such as the Pommereuil, France, EF4 tornado of June 24, 1967). In this case, the E-15 indicator should not be used, as it is not representative of the maximum intensity of the phenomenon.

EXAMPLES

Example of an **E-15** indicator without damage (**DOD 0**):

E-15 DOD 2 : Hyères tornado of November 5, 2017 (France). Damaged greenhouse, with covering mostly destroyed. © N. Gascard

E-16. TREES [TRE]

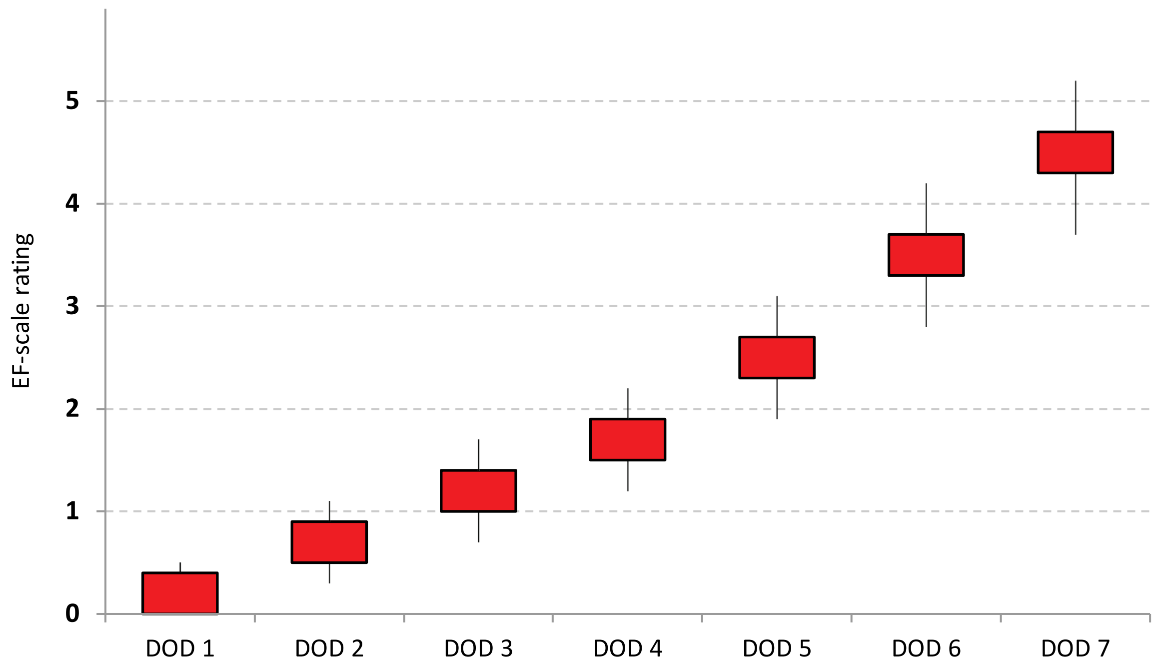
DESCRIPTION OF INDICATOR

Healthy and non-cultivated tree, hardwood or conifer, growing in isolation or on a copse, rooted in natural soil and non-waterlogged.

DEGREE OF DAMAGE (DOD)

DOD	Damage description
1	small branches snapped off, leaves torn off; minimal projection
2	large branches snapped; smaller branches carried over short distances (up to around 50 metres)
3	trees uprooted; large branches carried over short distances (up to around 50 metres); low girth trees are broken at mid height
4	trees uprooted or snapped; large branches carried over considerable distances (up to around 100 metres); tops carried over short distance (up to around 10 metres)
5	trees mostly snapped; large branches carried over distances of 100 metres and more; tree tops or entire trees carried over short distances (up to around 50 metres)
6	trees stripped, only trunks and the bottom largest branches remaining; branches of all sizes carried over large distances (up to several hundred metres); tree tops or entire trees carried over considerable distances (up to around 100 to 150 metres)
7	trees stripped, bark stripped; tree tops or entire trees carried over large distances (more than 150 metres)

POSITION OF DODS ON THE EF-SCALE



NOTES

- comments on tree species:
  - spruce, fir: use the low range for all DODs, except with specific configuration
  - palms and coconut palms: use the high range for all DODs
- comments on the environment:
  - cultivated fruit trees: use the low range for all DODs
  - trees in cultivated forestry plots (poplar groves,…): use the low range for DOD 4 and DOD 5
  - urban trees, planted under paved surfaces (avenues, long boulevards,…): preferably use the low range for DOD 4 and DOD 5
  - mature tree growing in non-cultivated mixed forest: preferably use the high range for all DODs
- comments on condition of trees:
  - young trees: preferably use the low range for all DODs
  - diseased tree: preferably use the low range for DOD 3
  - shallow-rooted tree: preferably use the low range for DOD 3
  - trees without leaves: preferably use the high range for DODs 1, 2 and 3
- comments on soil condition:
  - tree in waterlogged soil: preferably use the low range for DOD 3
- general comment: in the event of conflict between two opposing values, use the standard value

E-17. VINES [VIG]

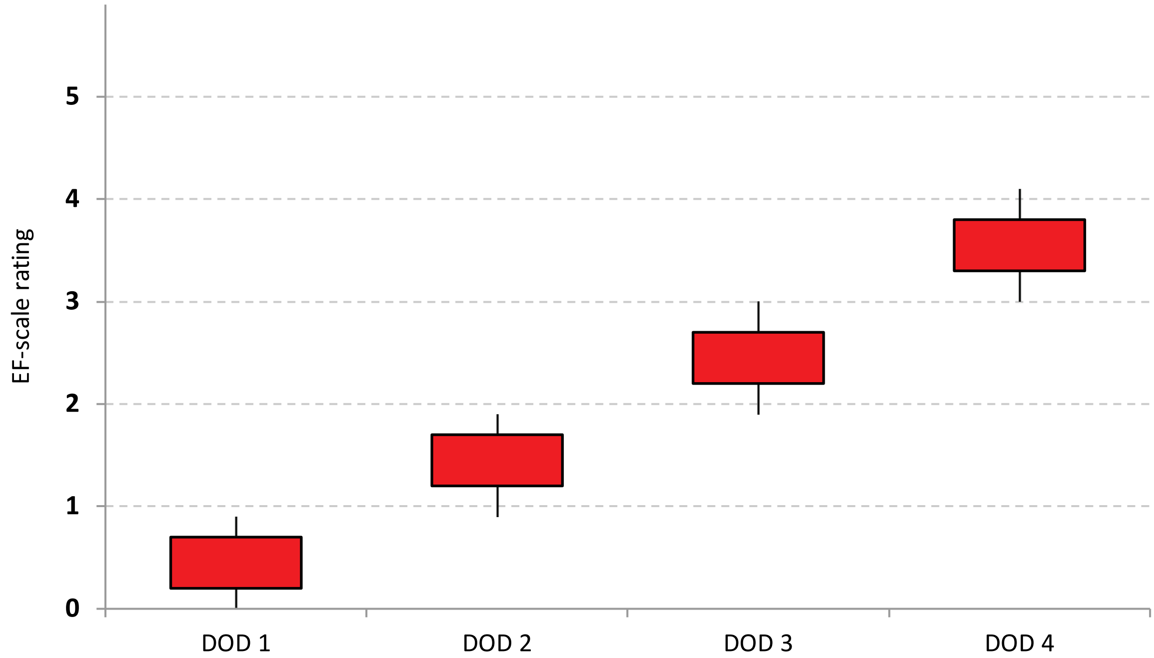
DESCRIPTION OF INDICATOR

Mature cultivated vines.

DEGREE OF DAMAGE (DOD)

DOD	Damage description
1	vines stripped and grapes torn off vines
2	overall damage to vine stocks; stakes blown over or sometimes carried off; some vines leaning or levelled
3	many vines blow over; stakes carried some distance away
4	vines broken, stocks torn out and carried away

POSITION OF DODS ON THE EF-SCALE



NOTES

- fragile and immature vine: use the low range for all DODs
- mature, strong vine: use the high range for all DODs

E-18. CEMETERIES [CEM]

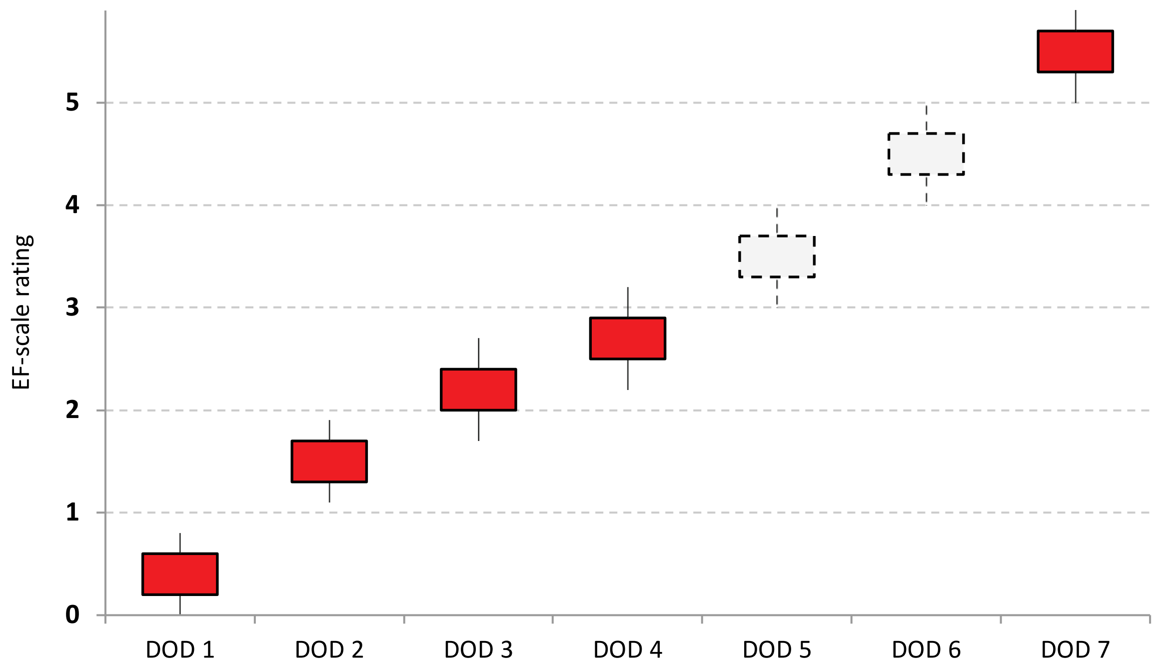
DESCRIPTION OF INDICATOR

Tombstones, headstones and other low funerary monuments made from hard materials (marble, sandstone, stone, concrete).

DEGREE OF DAMAGE (DOD)

DOD	Damage description
1	no visible damage to graves; funerary decorations blown away
2	crosses or funerary monuments leaning or levelled
3	crosses or funerary monuments moved/or broken
4	some tombstones lifted from the ground, graves uncovered, bodies exhumed
5	tombstones lifted from the ground and carried over some distance (up to 50 to 100 metres)
6	tombstones lifted from the ground and carried over long distances (100 to 200 metres)
7	tombstones lifted from the ground and carried over very long distances (more than 200 metres)

POSITION OF DODS ON THE EF-SCALE



NOTES

- old or poorly maintained funerary monuments: use the low range for all the DODs
- modern funerary monuments in excellent condition: use the high range for all DODs
- this indicator does not apply to complex funerary monuments (small chapels, altars,...)

EXAMPLES

Example of an **E-18** indicator without damage (**DOD 0**):

E-18 DOD 2 : Lorris tornado of March 5, 2017 (France). Steles leveled. © P. Mahieu, E. Wesolek / KERAUNOS.

E-19. MOTOR VEHICLES [VEH]

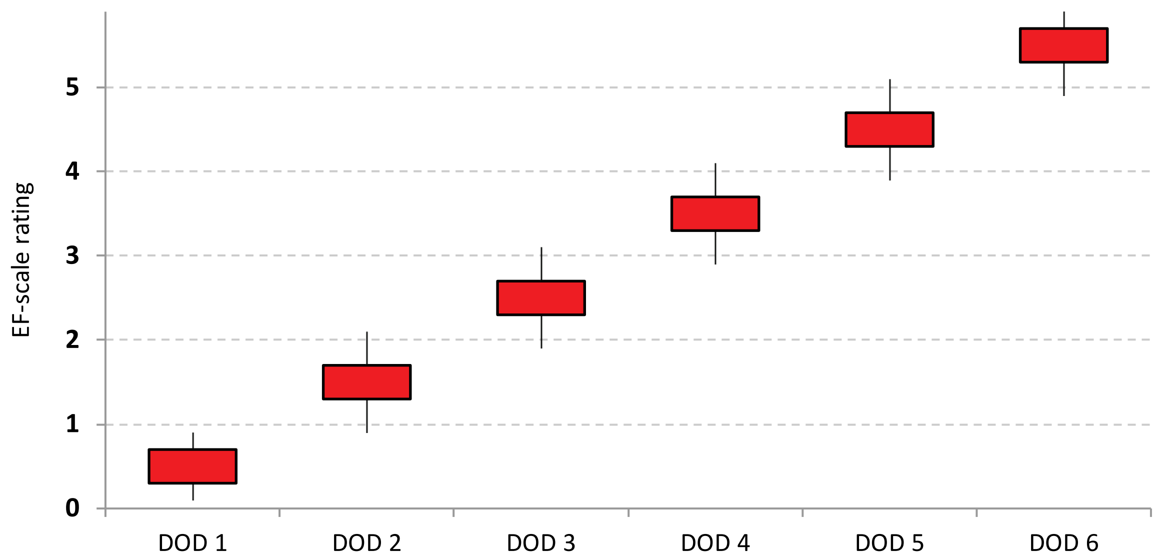
DESCRIPTION OF INDICATOR

Stationary motor vehicle, of any size: private vehicles, vans, pick-ups, articulated trucks, trailers, trucks, buses,…

DEGREE OF DAMAGE (DOD)

DOD	Damage description
1	vehicles sometimes shaken, but no direct damage; slight movement possible
2	cars and vans slightly moved; windows broken; trucks, articulated trucks, buses and other larger vehicles toppled
3	cars often moved, sometimes toppled or overturned; vans toppled or carried over short distance; agricultural vehicles (several tonnes) moved; articulated trucks sometimes lifted from the ground and carried over short distances
4	cars and vans moved or overturned; some vehicles rolled across the ground or even lifted from the ground and carried over distances (generally less than 100 metres); trucks, articulated trucks and other larger vehicles sometimes carried over longer distances
5	cars and vans lifted up and carried over large distances (usually 100 to 200 metres); trucks, articulated trucks and other larger vehicles sometimes carried over even longer distances
6	all vehicles moved and lifted up, often turning into missiles and thrown very large distances, generally over 200 metres, sometimes over 500 metres; trucks, articulated trucks and other larger vehicles sometimes carried over considerable distances (over 1 km)

POSITION OF DODS ON THE EF-SCALE



NOTES

- large vehicle, with a significant wind surface area, or light vehicle: use the <u>low range</u> for all DODs
- vehicle with a low wind surface area (aerodynamic shape), or heavy vehicle: use the <u>high range</u> for all DODs

EXAMPLES

E-19 DOD 5 : Pforzheim tornado of July 10, 1968 (Germany). Cars lifted up and carried over large distances. © Peter Zeller.

E-19 DOD 5 : Palluel tornado of June 24, 1967 (France). Car lifted up and carried over 60 meters. © Jean Dessens.

E-20. CARAVANS [CRV]

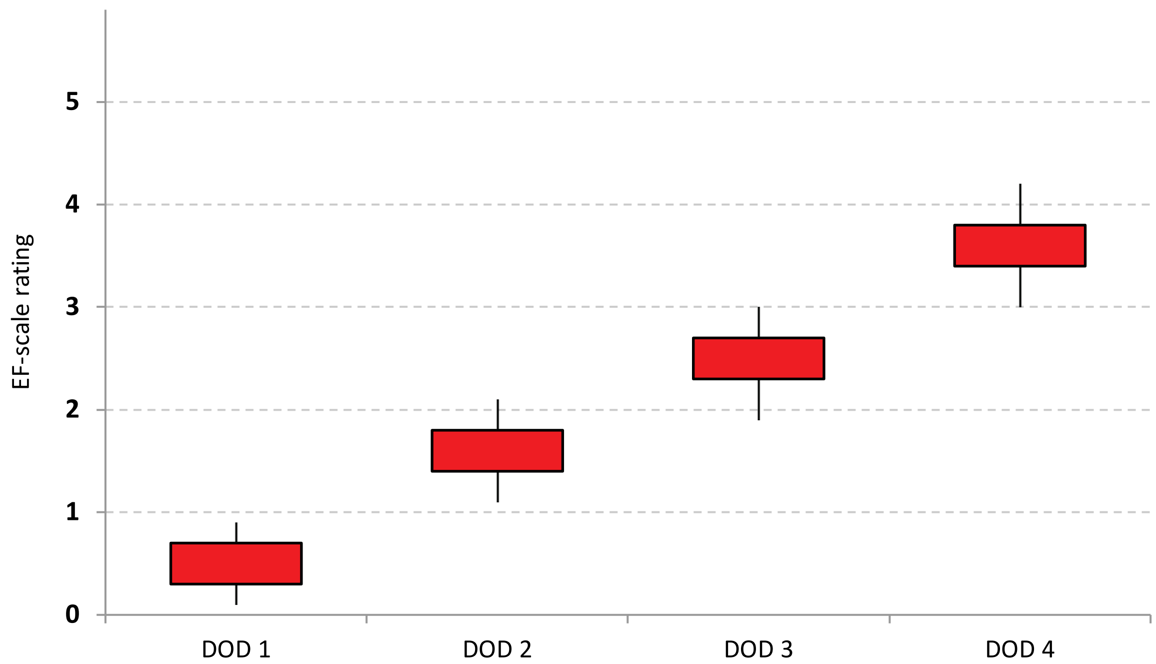
DESCRIPTION OF INDICATOR

Rigid caravans with total loaded weight of between 500 and 800 kg. Most common model of leisure caravan (80% of caravans).

DEGREE OF DAMAGE (DOD)

DOD	Damage description
1	empty caravans sometimes moved; windows broken or portholes loosened in certain cases
2	empty caravans pulled along the ground, toppled, overturned, even lifted up slightly; loaded caravans moved and sometimes toppled
3	empty caravans sometimes carried over some distance and sometimes destroyed; loaded caravans pulled along and overturned
4	all caravans, empty or loaded, lifted up, carried over distance and smashed

POSITION OF DODS ON THE EF-SCALE



NOTES

- lightweight and empty caravans: use the <u>low range</u> for all DODs
- heavy and fully loaded caravans: use the <u>high range</u> for all DODs
- this indicator does not apply to mobile homes; use the American indicators 3 and 4 in this case

EXAMPLES

E-20 DOD 3 : Ameland tornado of August 11, 1972 (Netherlands). Loaded caravans pulled along and overturned in a campsite. © Dutch National Archives.

E-21. HUMANS AND ANIMALS [LIV]

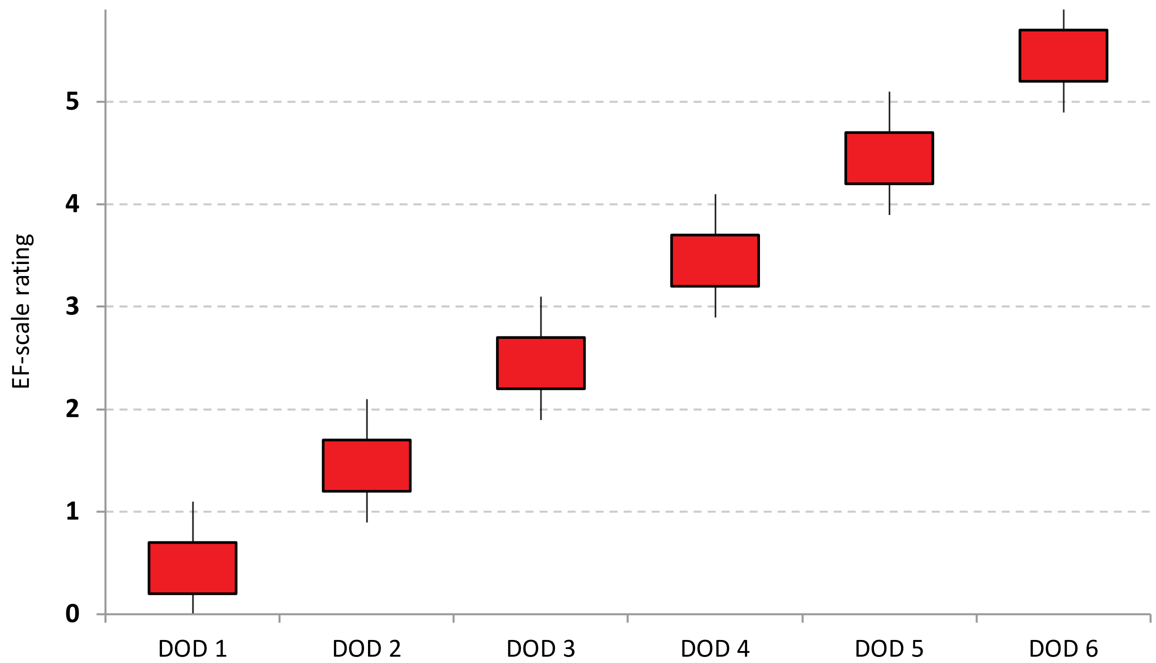
DESCRIPTION OF INDICATOR

Humans and animals.

DEGREE OF DAMAGE (DOD)

DOD	Damage description
1	adult humans and many animals buffeted but unharmed; light animals such as poultry generally knocked over or lifted from the ground.
2	adult humans pulled or rolled across the ground; birds sometimes injured; sheep and similar sized animals knocked over and slightly lifted from the ground; heavy animals (horses, cows, donkeys,...) buffeted
3	adult humans lifted from the ground and carried over short distances; birds sometimes decapitated; sheep and comparable animals lifted from the ground and carried over short distances; heavy animals (horses, cows, donkeys,...) thrown to the ground
4	adult humans, sheep and other comparable animals sucked up and thrown long distances (several dozen metres); birds sometimes shorn of feathers and people stripped of clothing; heavy animals dragged along the ground and or swept up into the air
5	humans and animals, even heavy, sucked up and thrown long distances (sometimes more than 100 metres)
6	humans and all animals thrown long distances (several hundred metres)

POSITION OF DODS ON THE EF-SCALE



NOTES

- children, farmyard animals, driving animals: use the low range for all DODs
- very heavy animals: use the high range for all DODs

E-22. CONTEMPORARY HOUSES AND ECOLOGICAL HOUSING

DESCRIPTION OF INDICATOR

Small collective buildings and multiple-storey houses of very recent construction, in accordance with current environmental standards: very solid structures with small windows, often with flat roof and no roof framework.

DEGREE OF DAMAGE (DOD)

This indicator is still under study. This type of building is too recent to have a representative damage reference.

E-23. CONTEMPORARY MULTIPLE-STOREY RESIDENTIAL HOUSING

DESCRIPTION OF INDICATOR

Collective buildings with several floors (typically 4 to 8), with concrete framework.

DEGREE OF DAMAGE (DOD)

This indicator is still under study. This type of building is too recent to have a representative damage reference.

E-24. AEOLIANS

DESCRIPTION OF INDICATOR

Classic modern tri-blade aeolian, with horizontal axis, non-domestic and generally grouped into aeolian parks.

DEGREE OF DAMAGE (DOD)

This indicator is still under study. This type of construction is too recent to have a representative damage reference.

REFERENCES

Doswell C., 2009: On the implementation of the enhanced Fujita scale in the USA. *Atmos. Res.*, 93, 554–563.

Environnement Canada, 2013 : Enhanced Fujita Scale Damage Indicators and Degrees Of Damage. http://www.yorku.ca/pat/research/dsills/papers/EF-Scale/EC_EF-Scale_DI-DOD_Guide_e_FINAL.pdf

Fujita T.T., 1971: Proposed characterization of tornadoes and hurricanes by area and intensity. Satellite and Mesometeorology Research Project Report 91, University of Chicago, 42 pp.

Fujita, T.T., 1981: Tornadoes and downbursts in the context of generalized planetary scales. *J. Atmos. Sci.* 38, 1511–1534.

Groenemeijer P., 2013 : ESSL position on EF-scale. European Severe Storms Laboratory. http://www.essl.org/media/publications/20130920_EFposition.pdf

Mahieu P., **Wesolek** E., 2011: Contribution to an European adaptation of the enhanced Fujita scale: analysis of damage caused by tornadoes in France. Conference paper, European Conference on Severe Storms 2011.

Minor, J. E., J. R. McDonald, and K. C. Mehta, 1977: The tornado: An engineering-oriented perspective. NOAA Tech. Memo. ERL-NSSL-82, 196 pp.

Wind Science and Engineering Center, 2004: A Recommendation for an Enhanced Fujita Scale (EF-Scale). Texas Tech University, 111 p.

Wurman, J., Alexander, C.R., 2005: The 30 May 1998 Spencer, South Dakota, storm. Part II: comparison of observed damage and radar-derived winds in the tornadoes. *Mon. Weather Rev.* 133, 97–119.

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DOCUMENT BACKGROUND

October 6, 2011: public presentation of 10 new European indicators

March 10, 2016: detailed publication of 21 indicators (this document)

January 21, 2018: publication on the Internet, in French and English versions

September 9, 2024 : minor revision and clarification of indicator E-1 (small sheds, barns and other outbuildings) [FBO]

March 2016