Because a blowing wind is not steady, the distribution of low pressure and high pressure areas on the roof and side walls can shift position and vary from moment to moment. As a consequence of this, a house will typically shake and vibrate in a high wind. The effect is similar to that observed when a flag flaps in the wind, or the flutter that occurs in airplane wings. It is the flutter or vibration caused by unsteady wind that usually causes poorly fitted windows to break out.

Because of all the foregoing reasons, when wind damages a residential or light commercial structure, the order of damage is usually as follows:

1. lifting of shingles.
2. damage to single pane, loose-fitting glass windows.
3. lifting of awnings and roof deck.
4. damage to side walls.

Depending upon the installation quality of the contractor, of course, sometimes items 1 and 2 will reverse.

Unless there are special circumstances, the wind does not cause structural damage to a house without first having caused extensive damage to the shingles, windows, or roof. In other words, the small stuff gets damaged before the stronger stuff gets damaged. There is an order in the way wind causes damage to a structure. When damages are claimed that appear to not follow such a logical order, it is well worth investigating why.

2.3 Variation of Wind Speed with Height

Wind blows slower near the surface of the ground than it does higher up. This is because the wind is slowed down by friction with the ground and other features attached to the ground, like trees, bushes, dunes, tall grass, and buildings. Because of this, wind speeds measured at, say 50 feet from the ground, are usually higher than wind speeds measured at only 20 feet from the ground. In fact, the wind speed measured at 50 feet will usually be 14% higher than the speed at 20 feet, assuming clear, level ground, and even wind flow. As a general rule, the wind speed over clear ground will vary with 1/7th the power of the height from the ground. This is called the "1/7th power rule."

$$v = k[h]^{1/7} \quad \text{(vi)}$$

where v = wind speed measurement, h = height from ground, and k = units conversion and proportionality constant.

For this reason, when wind data from a local weather station is being compared to a specific site, it is well to note that most standard wind measurements are made at a height of 10 meters or 32.8 feet. If, for example, it is necessary to know what the wind speed was at a height of 15 feet, then by applying the 1/7th power rule, it is found that the wind speed at 15 feet would have been about 11% less than that measured at 32.8 feet, all other things being the same.

If a wind speed is measured to be 81 mph at a standard weather reporting station, that does not automatically mean that a nearby building was also subject to winds that exceeded the code threshold. If the building was only 10 feet high, then the wind at that height would likely have been about 16% less or 68 mph, which is well below the code threshold. If there were also nearby windbreaks or other wind-obstructing barriers, it could have been even less.

Local geography can significantly influence wind speed. Some geographic features, such as long gradual inclines, can speed up the wind. This is why wind turbines are usually sited at the crests of hills that have long inclines on the windward side. The arrangement of buildings in a downtown area can also increase or decrease wind speed at various locations by either blocking the wind or funneling it. Thus, the wind speed recorded at a weather station does not automatically mean that it was the same at another location, even if the two sites are relatively close. The relative elevations, the placement of wind obstructing or funneling structures, and the local geography have to be considered.

2.4 Estimating Wind Speed from Localized Damages

One of the problems in dealing with wind damages is the estimation of wind speed when the subject building is located far from a weather reporting station, or is in an area that obviously experienced wind conditions different from that of the nearest weather station. In such cases, wind speed can actually be estimated from nearby collateral damage by the application of the Beaufort wind scale.

The Beaufort wind scale is a recognized system introduced in 1806 by Admiral Beaufort to estimate wind speed from its effects. Originally it was used to estimate wind speeds at sea. The methodology, however, has been extended to estimating wind speeds over land as well. The Beaufort wind scale is divided into 12 levels, where each level corresponds to a range of wind speeds and their observable effects. A brief version of the currently accepted Beaufort wind scale is provided below.

In reviewing the Beaufort scale, it is notable that tree damage begins to occur at level 8 and uprooting begins at level 10. However, most building

Table 2.2 Beaufort Wind Scale

Scale Value	Wind Range	Effects Noted
0, calm	0–1 mph	Smoke rises vertically, smooth water, no perceptible movement
1, light air	1–3 mph	Smoke shows the direction of the wind, barely moves leaves
2, light breeze	4–7 mph	Wind is felt on the face, rustles trees, small twigs move
3, gentle breeze	8–12 mph	Wind extends a light flag, leaves, and small twigs in motion
4, moderate breeze	13–18 mph	Loose paper blows around, whitecaps appear, moves small branches
5, fresh breeze	19–24 mph	Small trees sway, whitecaps form on inland water
6, strong breeze	25–31 mph	Telephone wires whistle, large branches in motion
7, moderate gale	32–38 mph	Large trees sway
8, fresh gale	39–46 mph	Twigs break from trees, difficult to walk
9, strong gale	47–54 mph	Branches break from trees, litters ground with broken branches
10, whole gale	55–63 mph	Trees are uprooted
11, storm	64–75 mph	Widespread damage
12, hurricane	75 mph +	Structural damage occurs

codes require a residential structure and roof to withstand wind levels up to 12. This means that the mere presence of wind damage in nearby trees does not automatically indicate that there should be structural or roof wind damage to a building located near the trees. Because kinetic energy increases with the square of velocity, a level 9 wind has only about half the "punch" of a level 12 wind.

2.5 Additional Remarks

Most of the major building codes do not simply use a single wind speed of 80 mph for design purposes. Within the codes there are usually multipliers that account for many factors, including the height and shape of the building, gusting, and the building class. For example, in the UBC a factor of 1.15 is to be applied to the pressure exerted by the wind when "important" buildings are being designed, such as schools, hospitals, and government buildings.

Generally, most codes require that public buildings, such as schools and hospitals, be built stronger than other buildings, in the hope that they will survive storms and calamities when others will not. Thus, when this factor is figured in and the calculations are backtracked, it is found that the actual wind speed being presumed is much greater than the design base speed of 80 mph, or whatever the speed.

Further Information and References

ANSI A58.1, *American National Standard Minimum Design Loads for Buildings and Other Structures,* American National Standards Institute. For more detailed information please see Further Information and References in the back of the book.

BOCA National Building Code, 1993 edition. For more detailed information please see Further Information and References in the back of the book.

Kansas Wind Energy Handbook, Kansas Energy Office, 1981. For more detailed information please see Further Information and References in the back of the book.

Peterson Field Guide to the Atmosphere, by Schaefer and Day, Houghton-Mifflin, 1981. For more detailed information please see Further Information and References in the back of the book.

UBC, International Conference of Building Officials, 1991 ed., Appendix D, Figure 23-1. For more detailed information please see Further Information and References in the back of the book.

Wind Power Climatology of the United States — Supplement, by Jack Reed, Sandia Laboratories, April 1979. For more detailed information please see Further Information and References in the back of the book.

Winds and Air Movement, in *Van Nostrand's Scientific Encyclopedia*, Fifth Edition, Van Nostrand Reinhold Company. For more detailed information please see Further Information and References in the back of the book.