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Solar modules on flat roofs – why worry about wind?

By David Carpenter

Roofs of low-rise buildings offer attractive installation options for solar arrays because otherwise underutilized spaces can be put to work powering the occupied spaces beneath the roof or generating valuable revenue through feed-in tariffs. Although such arrays may seem to spring up virtually overnight in many places, a local building code official must generally approve proposed solar installations before he or she will issue a permit. This approval process varies from one jurisdiction to another, but nearly all officials require that the structural engineer of record supply calculations demonstrating wind-worthiness of the installation.

Most local building codes reference a recognized model standard, such as Minimum Design Loads for Buildings and Other Structures (ASCE/SEI 7-05), produced by the American Society of Civil Engineers. These codes are intended to produce estimates for design wind loads on buildings and were not intended to apply to roof-mounted solar panels. Applying building code calculations to rooftop solar panels, therefore, requires that the engineer interpret the code in a way that he or she believes to be most appropriate. Permitting officials may not be familiar with the unique challenges posed by rooftop solar and may require that rooftop installations meet inappropriate wind criteria. Consequently, permitting for solar panels and arrays is currently a patchwork of varying approaches. Some approaches are likely to result in over-designed, expensive mounting systems, while less conservative methods may jeopardize the integrity of the installation and the safety of its physical surroundings, particularly in the case of ballasted solar panels. Because neither scenario supports widespread deployment of solar energy, businesses developing rooftop solar products need a basic understanding of the wind environment on low-rise building roofs.

A "low-rise building" refers to a structure of modest height and substantial girth: consumer retail stores, wholesale clubs, warehouses, and distribution centers are common examples. Low-rise buildings are characterized by large flat (or nearly flat) roofs. When a strong wind approaches a side of such a building, the structure forces the wind to flow up and over the top, as illustrated in Figure 1. The air does not, however, flow smoothly over the roof. Instead, it breaks away at the leading edge of the roof, leaving a zone of swirling air beneath it.

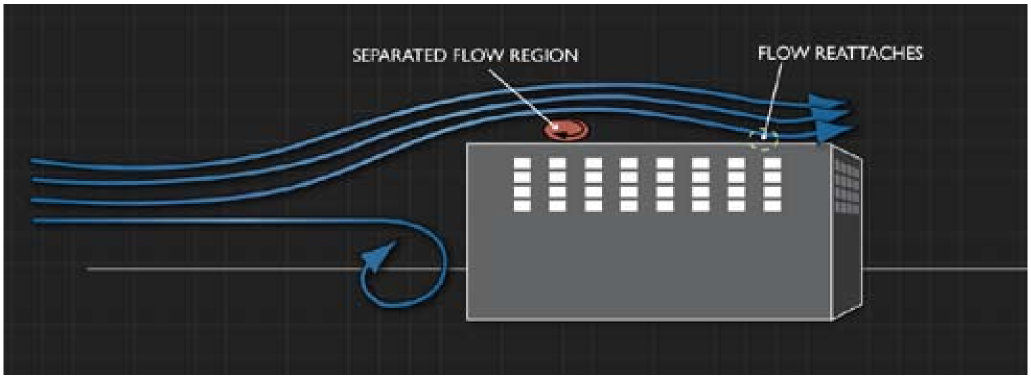

Figure 1: Flow separation and reattachment

This zone of swirling air is called a flow separation. If the building is large enough (and most low-rise buildings are), the wind above the building eventually comes back down and meets the roof. The point at which this happens is called the reattachment point, and although this point shifts around during a high wind event, on average it is located about twice the building height from the roof edge. Beyond the reattachment point, the wind once again flows parallel to the roof.

Figure 2 shows a wind zone map for the roof of a typical low-rise building. The light gray areas are dominated by flow separations: the wind can come from any direction, so there are four such zones. If we are concerned about loads on the roof itself, each of these zones is about half as wide as the building is high ($a \approx 0.5h$). However, if we are interested in solar panels mounted on top of the roof, the zones are about twice as wide as the building is high ($a \approx 2h$). The zones for the roof itself and for roof-mounted solar panels are of different widths because the two are vulnerable to different phenomena. The roof is mainly vulnerable to the difference between the pressure within the building and that above the roof. Solar panels mounted on the roof, on the other hand, are vulnerable typically to the speed of the wind approaching the panel. Although the suction exerted by a flow separation dies off rapidly with increasing distance from the roof edge, wind speeds do not behave the same way. Therefore, the edge zones for roofs and for solar panels are different.

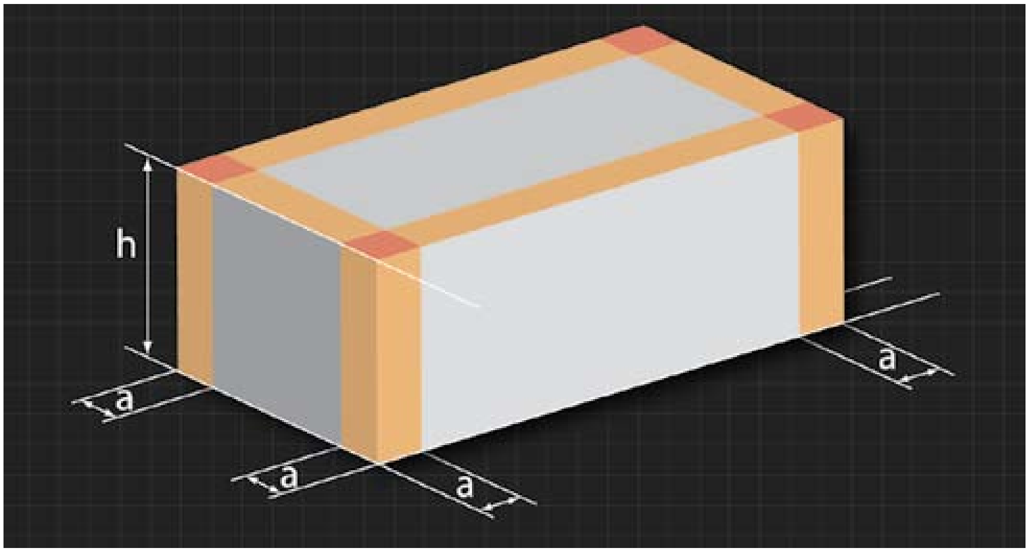

Figure 2: Wind zones for a flat roof

Now consider winds approaching the building obliquely, toward one of the corners. Oblique winds generate conical vortices above the roof. These vortices originate at the corner of the roof and radiate toward the middle of the roof. Rooftop corner vortices are identical to the vortices used by some fighter aircraft to generate lift at high angles of attack (see Figure 3).

Again, consider the roof zone map in Figure 2. The black areas in the corners are dominated by vortex development. The same phenomena that aerospace engineers employ to lift a fighter jet can destroy roof corners, so building codes require that these corners be especially strong.

Most solar panels mounted on the roof (and particularly tilted panels) are highly vulnerable to the speed of the wind speed approaching the panel. Corner vortices reattach to the roof with speeds 20-30% higher than that of the wind upstream, meaning loads in the corners can be 40-70% greater than those that solar panels in the middle of the roof would typically experience. As with the roof itself, these corner regions must be given special consideration when determining accurate wind loads for solar arrays, though for different reasons.

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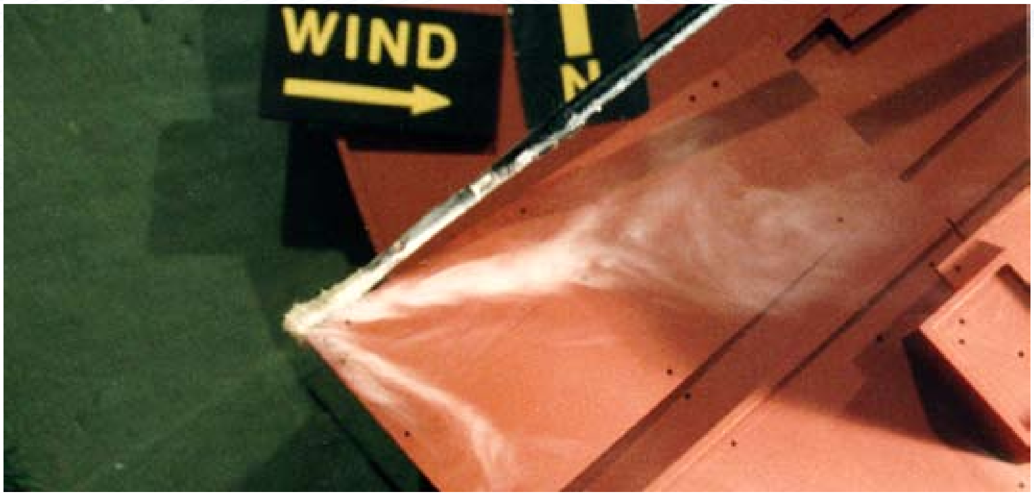

Figure 3: Corner vortices on a rooftop

Considering the wind characteristics discussed above, the roof can be thought of as having three distinct regions that concern solar panels:

1. **Roof interior:** This is the portion of the roof that lies more than two building heights from the edge. On some buildings, such as large distribution centers, this region can be substantial. For many buildings it is quite small and for others it may not exist at all. In this part of the roof, the wind travels along the surface of the roof, much as it does along the ground.
2. **Roof edge:** This is the portion of the roof parallel to the roof edge and lying within two building heights. Flow separation and reattachment dominate this region so the code calculations do not strictly apply (see the related paper, "How to Calculate Wind Loads on Solar Panels in the US"[1]).
3. **Roof corners:** These regions are highly volatile. Because of corner vortex development, the wind can approach a solar panel from nearly any wind direction, regardless of the direction of the main flow. Vortex reattachment creates wind speeds higher than that of the approach wind. Code calculations for these areas typically require additional safety/ uncertainty factors, and should only be considered as estimates .

The size and significance of these regions can vary due to panel geometry. For example, in the northern hemisphere most solar panels are tilted toward the south, which means that northerly wind approach angles are typically more critical than others. Depending on array geometry, some regions may all but disappear, while others grow in significance. It is important to understand how a proposed array will behave in light of the complex wind environment on the roof.

This paper has provided a short synopsis of the wind flow patterns above the roofs of low rise buildings with flat roofs. Similar flow patterns exist above gabled roofs, particularly near the roof peak. These flow patterns present designers of roof-mounted solar panels with significant wind-related challenges. An appreciation for the unique wind environment on the roofs of low-rise buildings is crucial when designing or approving any roof-mounted installation.

[1]Banks, David; "How to Calculate Wind Loads for Solar Panels in the US"
[2]Ibid.

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Dave is a Special Projects Engineer with CPP. He has been involved with numerous wind tunnel studies to determine design wind loads for a variety of roof-mounted and ground-mounted solar arrays and is versed in the applicability and limitations of ASCE 7-05 and Eurocode with respect to solar products. His interests include wind effects on solar installations, sustainable development, computational fluid dynamics, and high performance parallel computing.

References and Additional Reading

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