Title: The Receptivity of Roofs for Solar Panels

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Abstract:
The importance of roof design to host solar panels is increasingly recognized. Orientation, roof pitch, roof type, and a variety of obstructions all work to either make a roof receptive to solar panels, or difficult for solar panels to be installed, or something in between. This paper proposes a roof property which might be called receptivity, to characterize the degree to which a roof is or is not well-suited for solar panels. The characteristics of a receptive roof are explored. A scoring system is proposed for this property of receptivity. A variety of roof types are evaluated with the proposed scoring system, and a number of real roof examples are scored and examined. Best practices to encourage roof receptivity are offered.

Keywords:
solar, panel, roof, obstacle, receptivity

The Receptivity of Roofs for Solar Panels

1. Introduction

Roofs are a logical location for solar panels. Elevation reduces the risk of shading by the building itself, adjacent buildings, vegetation, or other sources of shadow. Limited access on a roof reduces the risk of vandalism and theft. Roofs can provide a ready-made structural support.

However, roofs are generally not designed or built to host solar panels. Roof orientation, relative to the sun, is often poor. Roof-mounted building components such as chimneys, plumbing vents, and fans often interfere with a good potential solar panel location. A study of a 40,000 square foot community center with a flat roof found obstructions reduced the available roof area for solar panels to 21% of the roof (Bryan, et.al, 2010). Dormers usually obstruct what could be large contiguous spans for solar panels. Roofs are broken into many sections, which furthermore make installation of adjacent panels difficult and more costly. Small sections of roof are often too small to host even a single panel. Portions of roofs are sometimes shaded by higher areas of roof, reducing their effectiveness as locations for solar panels.

In designing and installing solar panels, decisions are often made which limit solar panels based on available roof area. Furthermore, the cost of solar installations often increases as installers must adjust the installation to accommodate obstacles on roofs.

In the drive towards cost-effectiveness, the material costs of solar installations have been dropping, while there has not been an associated significant drop in the installation costs. For example, a substantial drop in the installed cost of solar photovoltaic systems from 2008 to 2009 is fully attributable to decreases in module price, indicating that non-material costs (labor) are not decreasing[a]. Rationalizing roof structures to be receptive to solar panels, and so dramatically simplifying installation costs, may be the biggest contributor to driving installed costs lower.

So, as solar panels are improved and optimized for energy performance and reduced cost, a parallel effort is needed with roofs, otherwise roofs become a weak link, increasing installed cost, reducing energy effectiveness, and limiting overall capacity. The trend toward substantial contributions of solar energy to energy supply, and even toward zero-energy, is in fact seriously hampered by inadequate siting locations for solar panels. Roof area has in fact been identified as a main limiting factor in achieving zero energy buildings, especially for taller buildings (Torcellini, et. al, 2006), and so obstructions on the roof become significant obstacles as zero energy is sought.

Solar photovoltaic installations are growing at a rapid rate. Solar thermal technologies are also well-proven, and are also growing. A large fraction of solar installations are on existing buildings, rather than new buildings where roofs can be optimized. So it is at this time that we need to think to the future, when so many solar installations will need to be installed on buildings which are being designed and built now.

At the same time, the aesthetics of solar panels on roofs are important, likely even more important than recognized. If we can design roofs to be aesthetically “receptive” to solar panels, we increase the chance that solar panels will be installed at all.

In this paper, we develop the concept of a roof's receptivity to solar panels. A discussion of roof types and "receptivity" to solar panels is provided, followed by the development of a "roof solar receptivity score". Various roof types and example actual roofs are rated according to the score, and an argument is made for using such a score to guide the design of buildings.

2. Roof Characterization

Roof types are broadly grouped into flat and pitched. Pitched roofs include simple shed roofs, gable roofs, hipped roofs, and often a combination of these on a single building. Figures 1-9 illustrate the most common roof types.

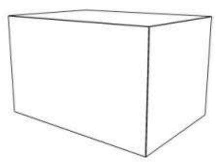

Figure 1 Flat Roof

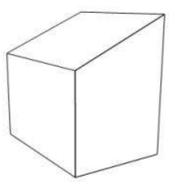

Figure 2 Shed Roof

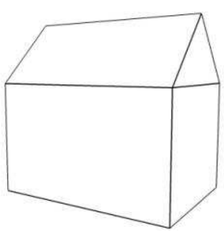

Figure 3 Gable Roof

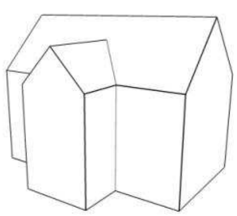

Figure 4 Cross Gable Roof

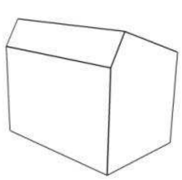

Figure 5 Saltbox Roof

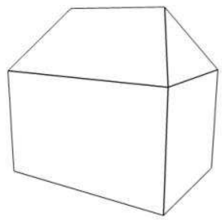

Figure 6 Hipped or Hip Roof

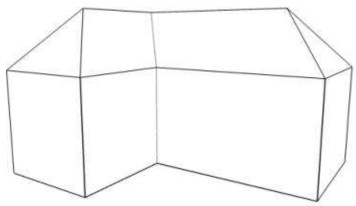

Figure 7 Cross Hipped Roof

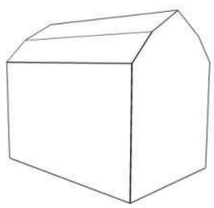

Figure 8 Gambrel Roof

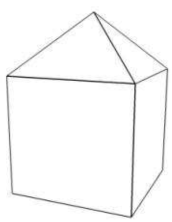

Figure 9 Pyramid Roof

Roofs typically have a variety of building components on them which obstruct the installation of solar panels. Almost all roofs have at least one plumbing vent which penetrates the roof. Commercial roofs often have roof-mounted fans. Other roof-mounted items include chimneys, antennas, gravity vents, satellite dishes, rooftop HVAC equipment, elevator penthouses, and more.

3. The Case for a “Roof Solar Receptivity Score”

How can we make roofs more receptive to solar panels? What if we could quantitatively score roofs according to how “receptive” they are in hosting solar panels? Imagine a score of 100 for a roof that is perfectly ready and receptive to host a roof full of solar panels, and a score of 0 for the most hostile possible roof environment for solar panels, such as a steep-shed-roof facing due north.

Such a score could serve several purposes:

1. To compare roofs
2. To set goals

3. To understand roofs, and to quantify the obstacles to solar panels on roofs
4. To guide improvements to roofs

Further purposes might be for green building incentive programs, to incentivize roof design and construction to maximize the possibility of mounting solar panels on roofs, whether at the time of construction or well into the future. Or, imagine a LEED credit awarded for a minimum “solar roof receptivity score”.

3.1 The Ideal Roof

As a preface to developing such a score, what are the characteristics of an ideal roof, for purposes of solar energy? Even though, like so many other things, “we know it when we see it”, an ideal solar roof is actually comprised of several different and important properties. These are:

1. Having a large area.
2. South facing.
3. Having a minimum area, sufficient in size to host at least one solar panel (although preferably many more).
4. No protruding elements like plumbing vents.
5. Rectangular (as opposed to having the triangular sections associated with hip roofs, dormer valleys, etc.).
6. No shading.
7. Built in a single section (contiguous)
8. Properly pitched
9. Structurally sound
10. Durable, to prevent the need to remove the solar panels for purposes of re-roofing

3.2 Guiding Principles for a Scoring System

A scoring system is best if simple, and fast to calculate for any particular roof. It must also capture the most important elements of what it scores, in this case a roof’s receptivity to solar panels. A scoring system need not necessarily be a predictor of performance, or in fact be optimized to predict or guide peak performance. We limit the focus of the scoring system to a building’s roof. The receptivity of a building to solar panels could easily be extended to vertical walls, or to the site/ground, but, for reasons of focus, we direct attention just to the roof. We also ignore adjacent buildings or shading by trees, again for purpose of directing our interest to the roof itself. The focus of the scoring system is on fixed panels (as opposed to tracking/movable panels). We also propose that it be independent of the application, for example whether the panels are being used for space heating, or electricity, or hot water, or a combination of these.

3.3 Proposed Scoring Methodology

The most important characteristic of a roof, to host solar panels, is quite simply roof area: the more area the better. So we start by broadly defining the roof solar receptivity score as the ratio of “receptive” roof area (still to be defined) to the total available roof area.

In the northern hemisphere, roofs should face south in order to receive sun. A north-facing roof gets no sun, a south-facing roof is ideal. So we proceed by discounting the score for a particular portion of roof if it does not face due south. For simplicity, if a roof faces south, its score does not get discounted. If it faces due north, it gets discounted by 100%, and anything in-between is discounted linearly. For example, a roof facing due east or west has its score discounted by 50%. It is important to recall that the roof receptivity score is not a predictor of solar performance or optimization, it is a broad score intended to reflect general receptivity to solar panels. So we can take liberties with simplicity, such as a simple linear discount for orientation.

How do we deal with small sections of roof, such as the roof of a small dormer? To be considered receptive, a roof should carry a solar panel completely, without the panel having to overhang any edge of the roof. To encourage this, we propose that any roof section must have a minimum size, otherwise it cannot count as being "receptive" roof area. Solar panels, whether photovoltaic or thermal, vary in size, typically from perhaps a minimum of 10 square feet, to as big as 50 square feet, and occasionally larger. An average size, based on a survey of panels in the SRCC Directory of Certified Solar Collector Ratings as well as photovoltaic panels, is about 30 square feet [b]. Arguments can be made for the minimum size not being too small, as this would imply a receptivity which is not the case for most panels, or not being too big and so ruling out smaller panels. Again, for simplicity, we accept the fact that there is no perfect minimum, and so we propose that the minimum be the average panel size, or 30 square feet. Any discrete section of roof area smaller than 30 square feet will not count as being receptive.

Next, we address protruding building elements, such as plumbing vents, roof vents, roof-mounted fans, and the like. Such elements obstruct the installation of panels, either preventing at least one panel from being installed, or raising the cost of the installation if the element needs to be moved. Building on the idea of a typical panel being 30 square feet, we choose to penalize the "receptive area" by one half of an average panel, or 15 square feet for each small obstacle on a roof. We further define a small obstruction as anything under 15 square feet. If an element is larger than 15 square feet (for example, a large rooftop HVAC unit), then the full area of the element is subtracted from the receptive area of the roof.

Most solar panels are rectangular. Triangular-shaped sections of roof present a challenge for rectangular panels. Installers are reluctant to let panels overhang the edge of triangular roof elements, for structural and aesthetic reasons. And so fewer panels are installed. This impact depends strongly on the relative size of solar panels and the triangular section. Small panels on a large triangle might fill up to 80% of the roof area, but larger panels on a small triangle can easily cover less than 40% of the roof area. Sticking close to our promise of a simple scoring system, we propose that triangular sections of roof be discounted by 50%, in terms of receptive area.

While we clearly excluded shading by external elements, such as adjacent buildings or trees, shading of portions of the roof by other elements of the roof does feel like fair game for penalizing the roof receptivity to solar panels. In an ideal world, such shading would best be quantified with a model, accounting for year-round shading, and accounting for the specific application. But we invoke simplicity again, and propose a very crude shading penalty:

1 .10% - partial shading to east or west

2. 30% - substantial shading to east or west, or partial shading to south
3. 50% - substantial shading to south

Substantial shading is defined as the height of adjacent obstruction above the roof is more than the width of the collector away from the obstruction.

A roof which is broken into many sections, through the complexity of the roof lines, presents a challenge to solar panels, as it limits integer numbers of panels, and also makes wiring more complex. With a mix of boldness and arbitrariness, we penalize the score by 4% for each separate section of roof on a building.

Roof pitch is important for optimized solar performance. However, optimized solar performance is strongly dependent on the application. Solar space heating favors a more vertical panel, solar space cooling favors a more horizontal panel, etc. Since our scoring system is proposed to be independent of the application, we reluctantly drop roof pitch from the receptivity score. Any pitch will count as a roof, except a vertical pitch (in other words, walls do not count).

Structural capacity and roof durability are also difficult criteria to wrestle with. A structure which cannot take the extra weight of a typical solar panel, perhaps 5 pounds per square foot, should be penalized. Likewise with roofs which are not rated for 30 years or more. We decided to drop these as factors, but keep them in mind as a possible future enhancement of the scoring system.

Translating the general approach into an algebraic score, we get for each section of roof:

Receptive roof area (as a percent) = A_R * (180 - S_A) / 180 * (1 - P_S)

Where:

A_R – receptive roof area, defined as any roof area over 30 square feet, with a 30 square foot penalty for each obstruction such as a roof vent, and a 50% penalty for triangular sections of roof.
Ps – shading penalty (see definition above)
S_A – angle from due south, in degrees

Now, we define the roof receptivity score (as a percent):

Score = A_{RT} / A_T * (1-(RS – 1)) *.04 * 100

Score – roof receptivity score (%)
A_{RT} – total of all the A_Rs for individual roof sections
A_T – total roof area
RS – number of separate roof sections. Note: If a section was discounted because it was too small, it does not get added to the total of separate roof sections.

3.4 An Example

An example illustrates the scoring system (see Figure 3). The rake is defined as the length of the sloped portion of the gable roof, and the eave is the length parallel to the horizontal edge of the roof.

A gable roof oriented east-west (gables facing east and west, main roof surfaces facing south and north) has a single roof vent on the south roof face, has a 40' eave and a 10' rake. The south-facing roof area has a "receptive" area of (40*10 – 30)*(180-0)/180*(1-0) = 370 square feet, where 40*10 are the roof dimensions, 30 is the penalty for the roof vent, and the angle from south and shading penalty are both 0. The north-facing roof has zero "receptive" area, because the angle from south is 180, so 180-180=0. The total roof area is 40x10x2=800 square feet. The receptivity score is 370/800 = 46%.

4. How Receptive Are Common Roof Types?

Probably the most common type of residential roof is a gable roof (see Figure 3). If one slope faces south and the other faces north, a simple gable roof (assuming no penetrations such as roof vents) will score 50% on the receptivity index.

fA simple hipped roof (see Figure 6), with its triangular elements, will always score less than 50%. The triangular elements are not receptive to the rectangular shape of solar panels.

An ideal roof shape is a south-facing shed roof (see Figure 2). In its simplest form, with no obstructions, a shed roof will generate a 100% solar receptivity score.

Interestingly, a flat roof also can score 100%. Obviously, a flat roof requires supports for the panels if the panels are not going to be laid flat. And a flat roof must address the issue of sloped collectors shading each other.

5. Example Roofs

Fifteen roofs, from buildings arbitrarily selected around the country, were scored for solar receptivity. Five buildings with gable roofs scored between 22% and 47%, with an average of 36%. Three buildings with hip roofs scored between 30% and 39%, with an average of 35%. Five buildings with flat roofs scored between 89% and 100%, and averaged 97%. One building with a combination of gable and flat roofs scored 61%.

Several actual solar installations were evaluated, specifically installations where there appeared to be an attempt to fill the roof with solar panels.

Figure 10 Chimney Obstructs One Panel on a Gable Roof

Figure 11 Angles Prevent Panels Filling a Hip Roof

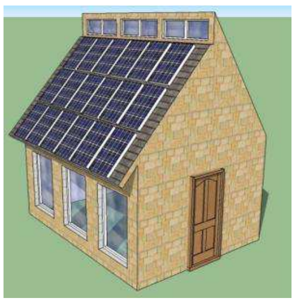

Figure 12 Roof Length Not a Multiple of Panel Width

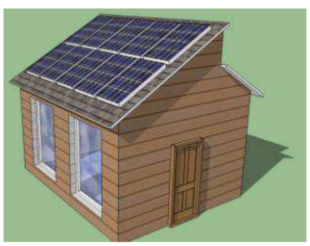

Figure 13 High Receptivity Due to Large South Roof and Small North Roof

Figure 14 Dormer, Plumbing Vent, and North Roof Result in Low Receptivity

In Figure 10, the chimney obstructs one panel. The gable roof still only scores a 48%, because the north side of the roof cannot be used.

In Figure 11, the angled sections of the hip roof prevent the rectangular panels from filling the roof, and the receptivity score is 38%, the unused north roof, and hip roof sections, also contributing to the low score.

In Figure 12, the large panels also do not fill the roof due to panel dimensions not being multiples of the roof dimensions. The receptivity score is 45%, primarily because of the unused north roof.

In Figure 13, a relatively high score of 65% is achieved, as the panels almost fill the south-facing roof, and the north-facing roof is small.

The example in Figure 14 scores a 40%. Again, the north roof hurts the score, and the dormer and the plumbing vent also lower the score.

6. Best Practices

Whether or not a scoring system is used, best practices for roof design to ensure receptivity for solar panels include:

1. Choose a highly-receptive roof design, in order of preference from high to low:
    a. Flat roof
    b. Shed roof
    c. Gable roof
    d. Hip roof
2. Locate all roof penetrations, such as plumbing vents, on north slopes of the roof, or on walls.
3. Minimize the use of dormers.
4. Avoid roof designs where one portion of a roof shades another portion of roof.
5. Avoid complex roof designs, such as valleys. Keep roof lines simple and rectangular.
6. Orient the main portion of roof to the south.
7. Design a structurally sound roof, which can take the added weight of collectors.
8. Choose a roof finish which is durable.

Conclusions

Some types of roofs, such as gable roofs and hip roofs, are intrinsically unreceptive to solar panels, even if one side is facing south, because of the unavailability of north-facing surfaces. Roof complexities, such as valleys, can further reduce receptivity to solar panels. Other types of roofs, such as shed roofs and flat roofs, are intrinsically far more receptive. Roof obstructions such as plumbing dormers, plumbing vents and other roof-mounted equipment and protrusions, can also significantly reduce receptivity. A proposed scoring system for receptivity might be used to characterize roofs. If buildings are designed with high receptivity, a variety of benefits might ensue, including greater capacity for solar energy per building, and lower installation cost due to simplification of the installation, and adjacency of panels.

Acknowledgements

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Footnotes

[a] U.S. Solar Industry Year in Review 2009, Solar Energy Industries Association, May 2010.
[b] Directory of SRCC Certified Solar Collector™ Ratings, Solar Rating and Certification Corporation, 2010

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