March 24, 2010

Building & Licensing Division
Community Development Services Group
City of Kingston
1211 John Counter Boulevard,
Kingston, Ontario
K7K 6C7

Attention: Mr. Steve Murphy

Dear Mr. Murphy,

Re: Structural Implications
Roof Mounted Solar Panels

1. Introduction

Over the last few years there has been a growing interest in the installation of roof-mounted solar panels on new and existing buildings. The Ontario Government has provided significant financial incentives for green energy initiatives, thereby driving demand for such installations.

Solar panels do, however, have a significant impact on the roof structure to which they are mounted. This report is intended to assist your department in understanding the potential structural implications of such installations. There appears to be a great misunderstanding in the industry regarding the effect of solar panels on a roof. Some systems claim to be very light and thus have so significant impact. Such statements are misleading, and so this report strives to clear up the issue.

This report was written specifically for buildings designed under the provisions of Part 4 of the Ontario Building Code. However, the general concepts are the same for Part 9 structures. In fact, buildings designed within the provisions of Part 9 may be particularly unsuitable for the additional loads imposed by solar panels due to the lower safety factors employed for such small structures. Roofs framed with light wood trusses should be approached with particular caution since such trusses and the truss connections are typically designed for only the basic uniformly distributed Part 9 snow loads and do not, therefore, respond well when the loads are increased or the pattern of application of the load is altered, as is frequently the case for solar panels installations.

The Ontario Building Code (OBC) specifies the loads for which roofs must be designed. The loads to be considered include the self-weight of the roof assembly itself and any equipment upon it, as well as loads due to human activity, wind forces, snow and rain[1]. When solar panels are added to an existing roof, there are a number of factors which must be evaluated, beyond simply the additional weight of the panels themselves. We shall attempt to explain in general terms the considerations which must be given when determining whether an existing roof is suitable for the installation of solar panel arrays. The analysis herein is generic in nature – loads and effects will differ depending on the panels used, and the layout of the roof supporting them.

2. Snow Load Considerations

The OBC 2006, Part 4, requires that roofs be designed for the 1-in-50 year ground snow load, modified by a number of factors which are intended to account for the roof's exposure to wind, its slope, and its shape, as well as its importance. The actual formula is as follows:

$$S = I_s\,[S_s\,(C_b C_w C_s C_a) + S_r] \qquad \text{[OBC §4.1.6.2]}$$

where,

I_s = importance factor for snow load,
S_s = 1-in-50-year ground snow load,
C_b = basic roof snow load factor,
C_w = wind exposure factor,
C_s = slope factor,
C_a = shape factor, and
S_r = 1-in-50-year associated rain load, in kPa.

An explanation of some of these factors that may be applicable to a solar panel installation follows.

2.1. Wind Exposure Factor, C_w:

The factor C_w, from the formula given above, is intended to account for the degree to which the roof in question is exposed to wind. Areas of roof exposed to wind on all sides, with no significant obstructions, are found to accumulate a lesser degree of snow than sheltered or obstructed roofs. This is due in large part to the effect of wind sweeping across the surface and removing a portion of the snow. For this reason the OBC permits a reduction of 25% in the snow loads in such a case.

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[1] Seismic loads are also a consideration for the design of buildings. However, seismic effects have not been included in this study since they are not of significance to the installation of the photovoltaic panel arrays in the particular cases under consideration in this study.

However, the installation of solar panels on a previously unobstructed roof will negate this permitted reduction. Existing roofs designed using this factor would typically require reinforcement due to the consequent increase in the design snow loads.

2.2. Slope Factor, C_s:

The slope of a surface is a factor to be considered in determining the design load for snow on a roof or other structure. Surfaces having a slope of 30 degrees will tend to shed snow and so a reduction in the design snow load for such roofs in permitted. In the case of an unobstructed slippery roof, the reduction is even greater and may be applied to surfaces having a slope of greater than just 15 degrees.

If solar panels are placed on a formerly unobstructed sloped roof, the use of these slope factors may no longer be appropriate. If a roof was previously designed as an unobstructed slippery roof, the introduction of solar panels may result in increased accumulations of snow and the roof may, therefore, require reinforcement.

Furthermore, solar panels themselves are typically sloped and are usually relatively unobstructed and slippery. When arrays of solar panels are placed on a flat roof, the snow will land upon the panels and then slide off them into a pile beneath the low end of the panel. The structural commentaries to the Code[2] require roof areas below upper sloped surfaces which may shed sliding snow to be designed for these patterns of accumulation. This may result in patterns of snow accumulation on the roof for which it was not originally designed and may necessitate reinforcement.

2.3. Shape Factor, C_a:

The distribution of snow on a roof depends greatly on the roof's shape and the presence of any obstructions on it. When wind encounters obstructions (i.e. a high roof next to a lower area, a parapet wall, roof-mounted equipment, or solar panels), regions of accelerated and retarded airflow result. A minimum wind velocity is required to transport the snow, and so it tends to settle out in regions where the flow velocity is impeded, and it forms drifts. The weight of snow in these drifts may be significant and is often much greater than the snow load over an unobstructed roof.

The shape factor accounts for the shape of the drifts which are likely to form next to an obstruction such as a solar panel. Large solar panels will induce drifting snow

[2] User's Guide NBC 2005, Structural Commentaries (Part 4 of Division B), Canadian Commission on Building and Fire Codes, National Research Council of Canada, 2006, Ottawa, Commentary G, Paragraph 41.

for which the roof may not have been originally designed, thereby necessitating reinforcement.

The code recognizes that small obstructions do not cause significant drifting. In the Kingston area[3], snow drifting adjacent to obstructions that are either less than 1.247m high or less than 3.129m long may be neglected.

Many solar panels are less than the height that would induce drifting snow, or, in the case of small arrays, may be less than the length limits. However, in any case where both of these limitations are exceeded, snow drifting will be induced for which the original roof may not have been designed, resulting in the need for reinforcement.

2.4. Snow Load Distribution:

The presence of post-mounted solar panels will tend to alter the distribution of snow on the roof. Typically, the design of a roof structure for snow would consider its weight as being a uniformly distributed pressure. However, where solar panels or other equipment is elevated on discrete posts, those snow loads are delivered to the supporting structure at the post locations as concentrated loads. This form of load application may result in localized overstress of the supporting deck of structural framing members due to its concentrated rather than distributed nature. It is important to include this consideration when analyzing the capacity of an existing roof structure to support a solar panel array.

3. Wind Load Considerations:

The building code requires that buildings and portions thereof be designed for pressures and suctions due to wind acting on all or part of a surface. It is based on a reference velocity pressure that is a site-specific parameter determined from recorded wind speed data and formulated to provide a probability of being exceeded in any one year of 1-in-50. This is loosely referred to as the 1-in-50 year wind.

3.1. Methods of Wind Load Determination:

There are three different procedures recognized by the Code for determining the design wind load on buildings. The first is referred to as the Static Procedure. It is the most commonly used method and is appropriate for most low- and medium-rise buildings and for the design of smaller elements such as cladding and

[3] The calculation for the shape factor for a roof obstruction is dependent on the 1-in-50 year ground slow load, S_s, which varies by geographical location. The values given in this report are for Kingston only and may not be applicable to other locations.

appurtenances. It is the method commonly applied to solar panels and is the technique used in this report.

The second method is the Dynamic Procedure. It is intended for the overall wind effects on a building and is not considered appropriate for smaller elements such as solar panels.

The third procedure for the determination of the appropriate wind design loads is the Experimental Procedure. This method consists of wind tunnel testing or other experimental methods. The experimental procedure is well suited for non-standard applications and would be a good method to apply to the determination of the effects of various arrangements of solar panels on a building. However, such site-specific testing is costly and is not, therefore, practical for most applications. The use of non-project specific test results should be used with great caution as they may prove to be non-conservative if used in situations that were not specifically modelled in the testing.

3.2. Wind Forces – Static Procedure:

The design pressure or suction is calculated using formulae provided in the Ontario Building Code and in the Structural Commentaries to the National Building Code of Canada. The applicable formula is as follows:

$$p = I_w q C_e (C_g C_p \pm C_{gi} C_{pi})$$ [OBC §4.1.7.1]

where,

- p = the specified external pressure acting statically and in a direction normal to the surface, either as a pressure directed towards the surface or as a suction directed away from the surface,
- I_w = importance factor for wind load,
- q = the reference velocity pressure,
- C_e = the exposure factor,
- C_g = the external gust effect factor,
- C_p = the external pressure coefficient averaged over the area of the surface considered.
- C_{gi} = internal gust effect factor, and
- C_{pi} = the internal pressure coefficient.

The code specifies that the wind pressures and suctions to be used in the design of buildings and elements thereof shall utilize the specified reference wind velocity pressure, modified to account for variations in pressure that occur over the surface of an element exposed to wind. Significantly higher pressures are found to exist at corners and edges of surfaces, and the pattern of such forces varies with wind direction. Furthermore, the slope and geometry of the surface have an effect on the magnitude and distribution of the pressure over a surface. The code uses pressure coefficients, C_p, to account for these variations. These are non-dimensional ratios of actual wind-induced pressures.

A gust factor is also applied to the reference wind velocity pressure to account for random fluctuations resulting from turbulence in the approaching wind and that arising by the wake of the structure. For small elements, the gust factor is taken as 2.5.

The degree to which the building, or parts thereof, are exposed to the wind is accounted for in the exposure factor, C_e. This factor accounts for the fact that wind forces increase with height above grade. They are also affected by the terrain of the region. Wind loads in built up areas are somewhat lessened whilst those in open windswept areas and near large bodies of water are greater.

3.3. Effect of Wind on Solar Panel Arrays:

Wind pressures acting on a roof mounted solar array will, depending on locale, sometimes be subjected to fairly significant forces acting either in a downwards or upwards direction, and also in a sideways direction. Even panels oriented parallel to the roof surface are exposed to pressures and suctions acting normal to the surface of the panel. When downward pressures are exerted on the panels, these forces are transmitted into the building structure. In the case of panels supported on posts, this results in concentrated loads where there were none before. The pressure must be added to the weight of the panels when assessing the effect on the supporting structure.

The actual pattern and magnitude of wind pressures acting on a complex arrangement of rows of panels is difficult to confidently predict without project specific wind tunnel testing. Some argue that it is reasonable to assume that some shielding effects arise within the rows of panels, while other literature cautions that the turbulence created between rows of panels can result in unanticipated forces. For this reason, caution is recommended, and has led the International Building Code to specifically prohibit any decrease in the wind load due to the effect of shielding afforded by other structures[4].

In the case of a net uplift, some means of counteracting these forces must be provided. This entails either fastening the panel frames to the structure or overcoming the uplift by the use of ballast. The latter method has the benefit of

[4] International Building Code 2006, International Code Council Inc., Country Club Hills, IL, Section 1609, "Wind Loads", clause 1609.1, p.289.

not, typically, requiring any penetrations through the roofing membrane. However, it results in a much greater weight on the roof due to the ballast and typically results in the need for reinforcement of the roof structure. Fastening the panels to the structure is preferable, structurally, and the number of penetrations through the roofing membrane may be minimized through the use of transfer beams on the roof to which the panel frames are fastened. This does, however, have the effect of accumulating the loads and so the greater concentrated force is likely to require localized reinforcement of the building structure. Even in cases where each panel is individually secured to the structure, reinforcement may still be required. Furthermore, such fastenings must typically be made to more than just the roof deck, and often results in the need to remove ceilings in order to properly connect to the primary and secondary framing members themselves.

Some panel systems claim to be "self-ballasted". For such a system to truly require no positive mechanical attachment to the building structure it would necessitate a fairly heavy panel system (in the order of 37 psf). Such a system would likely exceed the capacity of most roof structures unless they had been purposely designed for such additional loads. Some systems claim that anchorage may be provided just at the parapets, to avoid penetrating the membrane. Caution must be exercised with such a system since the roof parapets on a building are often non-structural components and may not be reliably secured to the building structure to resist the concentrated loads that would be imposed by the solar array system.

Panel frames supported on posts that rest on the surface of the roof, either on a base plate or on a sleeper, must be checked to ensure that the concentrated pressure exerted does not damage the roofing membrane or crush the roof insulation.

4. Building Code Provisions for Existing Buildings

The Ontario Building Code is periodically revised and the provisions within it change from time to time. In the case of wind and snow loads, there have been a series of changes over the years. The latest revision to the Code came into force on the last day of 2006. In it there were increases to the snow and wind forces for which buildings must be designed, and new combinations of load to be considered. Fortunately, the Code is not retroactive and thus existing buildings need not be upgraded each time the code requirements change. However, when new alterations, additions or modifications to an existing building are carried out that effect the existing structure, upgrading may be required.

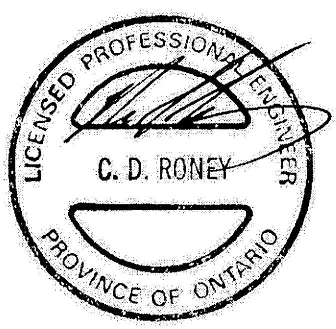
The OBC describes this concept in terms of the building's *Performance Level*. It states that the performance level of a building after construction or alterations shall not be less than the performance level of the building prior to construction. In simple terms this means that if you add any new loads to a structure for which it was not originally designed, then it is a requirement to reinforce those portions of the building so effected to restore the building's structure to a level of safety that meets or exceeds the level that existed prior to the work[5].

5. Conclusions

The installation of solar panels on the roof of a building typically induces significant additional loads. The magnitude of the loads imposed depends greatly on the geometry of the panels, as well as the exposure and construction of the existing roof. **The vast majority of existing building roofs, unless specifically designed for such installations, will require reinforcement to support the structurally-significant loads imposed by solar panel arrays.**

Competent analysis of the load effects of a solar panel installation on an existing roof structure, or a new one for that matter, is extremely important. Claims by solar panel manufacturers that their system is 'self-ballasted' or otherwise requires no reinforcement of the existing structure should be critically examined. A structural engineering analysis should be carried out in all cases to fully assess the load effects of solar panel installations and the capacity of a roof surface to safely resist such effects.

RONEY ENGINEERING LTD.



Chris D. Roney, P.Eng., BDS, FEC

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[5] Where conditions are found to be unsafe by modern standards, upgrading is required even if the performance level is unaffected.