Snow and freezing water on roofs

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SUMMARY
Snow on roofs can give problems in the winter. Snow can melt on the roof from the heat loss from the building and the melting water can freeze on the overhang and give risk for ice dams. The rest of the water will drip and can form icicles. A model has been made for this process. Results of a parameter study are presented. A short overhang increases the risk for icicles. A long overhang reduces the risk for icicles but increases the risk for ice-dams.

KEYWORDS
ice, snow, physics, roofs and climate

INTRODUCTION
A typical winter problem is snow and ice on roofs. This includes a number of problems that are related to building physics and heating of the house. Sloped roofs with external gutters can give problems as seen in figure 1. An example is melting of the snow on the roof and the freezing of the water on the overhang. The result is generation of an ice layer along the eaves. The ice layer can result in ice dams, so that melting water is collected behind. As the water do not freeze on the roof will it give a water pressure on the lower part of the roof. This gives a risk for water leakage into the building if the roof is not watertight. Another example is icing and generation of icicles on the roof edges.

Figure 1. Building with icicles and icing on the overhang.

Icicles hanging from the eaves are a serious problem as they can fall down and hit people walking beneath. The impact of a falling icicle or ice from ice dams can in the worst case kill people. Such incidents have happened in Sweden and Norway. According to Swedish law, it is the owner of the building who is responsible for prevention of sliding of snow and ice from the building. The Swedish Association of Buildings Owners (Fastighetbranchens Utvik-lingsforum) has made a report (Snö och is på tak 2004) about the problems of snow and ice on roofs. It describes some law cases and examples of contracts with a firm to remove the ice and icicles, when they form in the winter. It is very helpful for the building owner as a basis for reducing the risk of snow and ice problems but it only sketches the physics behind the problem. A better solution is to prevent or at least reduce the risk by a better knowledge of snow melting, freezing and icicles generation on roofs. The problem with icing and icicles on roof is a complex problem involving architecture, meteorology, glaciology and building physics.

ROOF TYPES AND SNOW ON ROOFS

We can divide roofs in two types: cold (ventilated) roofs and warm (non-ventilated) roofs. In warm roofs, it is normal to have internal drainage with downpipes in the building. This solution has no or very little risk for icicles. Freezing of the melting water on the roof can still be a problem. Ventilated roofs introduce a ventilated gap or roof space to prevent moisture problems and to keep the surface of the roof cold. These roofs are in most cases sloped. The drainage is external to gutters along the eaves and to downpipes. The result is a high risk of ice formation on the overhang at the eave and icicles formation if the melting water freezes for instance in the gutter.

We can calculate when the snow thickness is so high that the snow begins to melt because of the heat loss from the building. Calculations for glass roofs were made in handbook for glass roofs (Dreier et al, 1985; Nielsen, 1988). Table 1 shows the calculation for different U-values for new snow density 100 kg/m^3 and old snow 300 kg/m^3. The indoor temperature is 20 ^{o}C and the outdoor temperature is –10 ^{o}C. The snow density and the U-value of the roof are important. For glass roof where the minimum snow thickness is very low, will the snow start to melt very fast and in that case slide down the roof. For a new normal Scandinavian well-insulated roof with a U-value of 0.15 W/m^{2}K the minimum thickness is so high that melting from below is of minor importance at this outdoor temperature. For lower outdoor temperatures and/or higher indoor temperature the melting from the heat loss will from the building be important. For old houses the snow melting is a problem as the insulation was much lower and the U-value higher.

Table 1. Minimum snow thickness giving melting from the building heat loss

U-value W/m^{2}K	Glass 3.0	Glass 1.9	Roof 0.3	Roof 0.2	Roof 0.15
New snow λ = 0.06 W/mK	0.5 cm	1 cm	8 cm	12 cm	16 cm
Old snow λ = 0.26 W/mK	2.5 cm	4.5 cm	37 cm	56 cm	75 cm

MELTING FREEZING AND DRIPPING

For a sloping roof with overhang we can calculate the amount of melting water on the roof based on the energy balance. This amount of water can freeze on the overhang part of the roof or it can drip to generate icicles. If there is no overhang then all the melting water will drip and be able to generate icicles. If we have an overhang where we have freezing temperatures above and below zero, then all the melting water or part of it will freeze on the overhang. The rest of the water will be dripping and could generate icicles.

We use a reference case to show the effect of different parameters on the amount that will melt, freeze and drip. The roof is 7 m long with slope, so the water can run down the roof to the overhang at the eaves. The outdoor temperature is –10 ^{o}C and the indoor temperature is 21 ^{o}C. The U-value of the roof is 0.5 W/m^{2}K as an old building. The snow thickness is 20 cm with a thermal conductivity of 0.06 W/mK. That is a snow density of about 200 kg/m^3. The overhang has a length of 0.4 m and a U-value of 10 W/m^{2}K with very little thermal insulation in the overhang.

Figure 2 shows the effect of variation in the roof length. All other data are from the reference case. The amount of melting water will increase with the length of the roof. The amount of water that can freeze on the overhang has a maximum value that is reached for a roof length of 6 m. If the roof length is below that value, then all the melting water from the roof will freeze on the overhang and we will not get icicles. If the length is higher than 6 m then part of the water will be dripping, and more so the longer the roof is. The amount of icicles will increase with the length of the roof. The sizes of icicles will depend on the water flow at the root of the icicles. If the water flow is low then the icicle will increase in thickness but not in length. If the water flow is high then the water could melt part of icicles as discussed in Nielsen (2008). Later we will combine this melting, freezing and dripping model with the model for icicles generation.

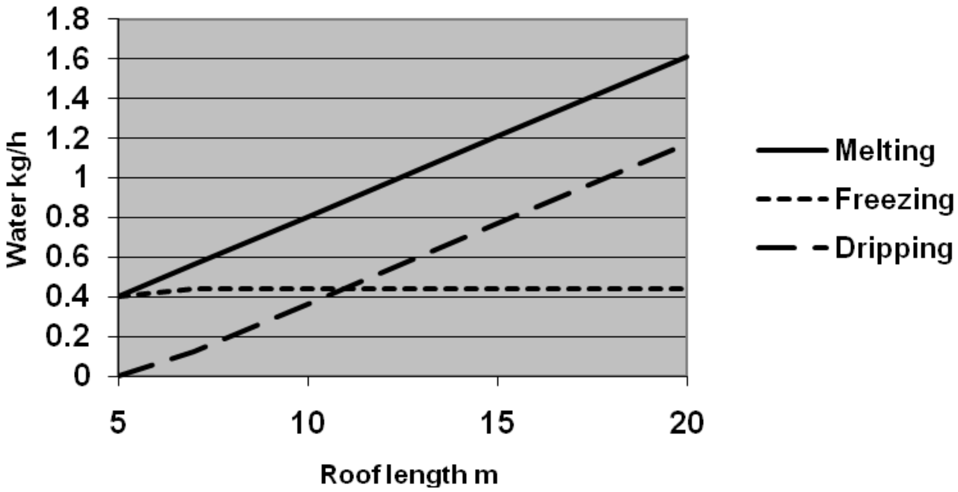

Figure 2. Calculated melting water from the roof with variations in roof length. The amount freezing on the overhang and the dripping at the eaves are shown.

Figure 3 shows the effect of variations in the length of the overhang for a 7 m roof. The amount of melting water from the roof will be constant. The variations come in the amount of freezing on the overhang. This will increase until all the water from the roof freeze on the overhang. That will happen for an overhang length of more than 0.5 m. The dripping that can generate icicles will be reduced when the overhang is increased. For a length of more than 0.5 m will there be no dripping. The practical aspect of this is that it is not a good idea to have no overhang as all the water has the potential to generate icicles. It is neither a good idea to have a long overhang, as all melting water will freeze on the overhang. This will give an extra load on the overhang and a risk that this frozen ice will fall down from the roof, when the temperature goes above 0 ^{o}C. This can be prevented with the use of snow guards.

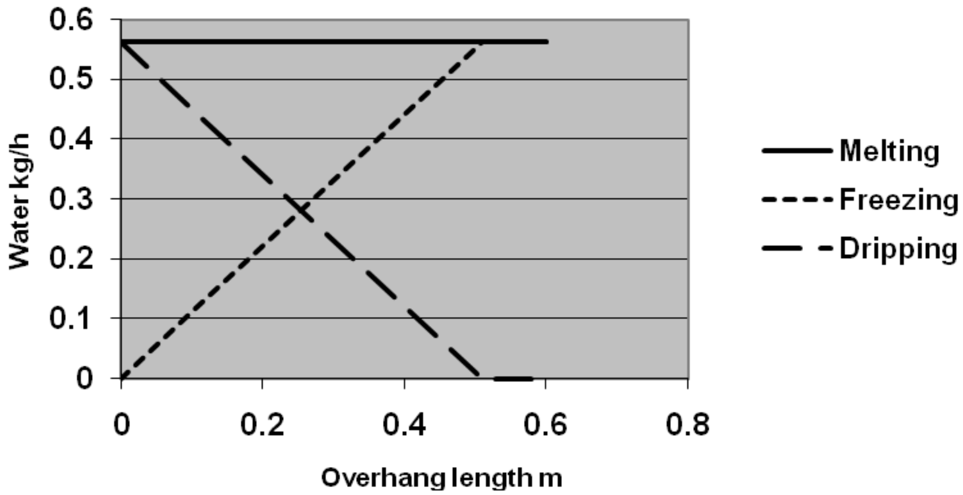

Figure 3. Calculated melting water from the 7 m roof with variations in overhang length. The amount freezing on the overhang and the dripping at the eaves are shown.

Figure 4 shows the effect of variations in the outdoor temperature. The amount of melting water will increase with higher outdoor temperatures. If the outdoor temperature is below –15 ^{o}C , then all the melting water will freeze on the overhang. With higher outdoor temperatures will the water dripping increase and the amount of water freezing will decrease. In cold weather is there no risk of icicles generating as all the water will freeze on the overhang.

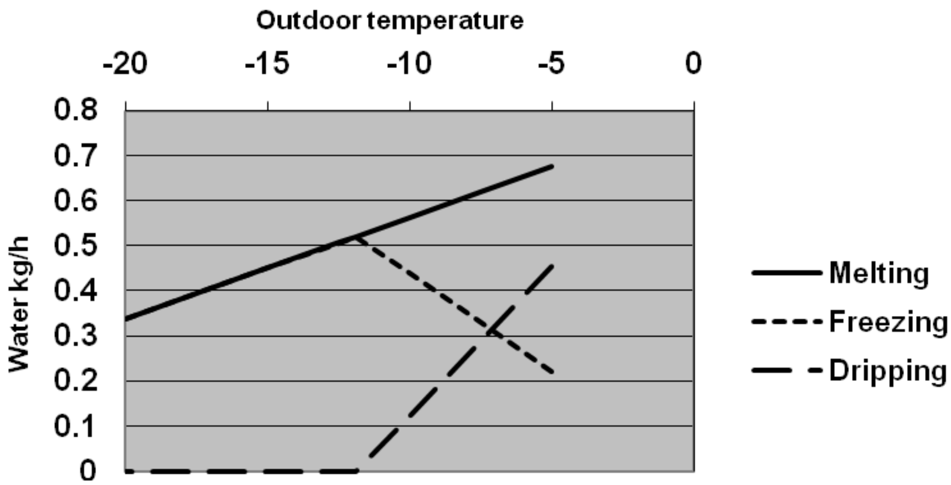

Figure 4. Calculated melting water from the 7 m roof with variations in outdoor temperature. The amount freezing on the overhang and the dripping at the eaves are shown.

Figure 5 shows the effects of variations in snow thickness on the roof. For higher snow thickness the melting of water will increase. If the snow thickness is below 15 cm, all the melting water will freeze on the overhang. For a thickness above 15 cm the amount freezing on the overhang will be constant. The dripping will increase with an increase in the snow thickness and with that an increased risk of icicle generation.

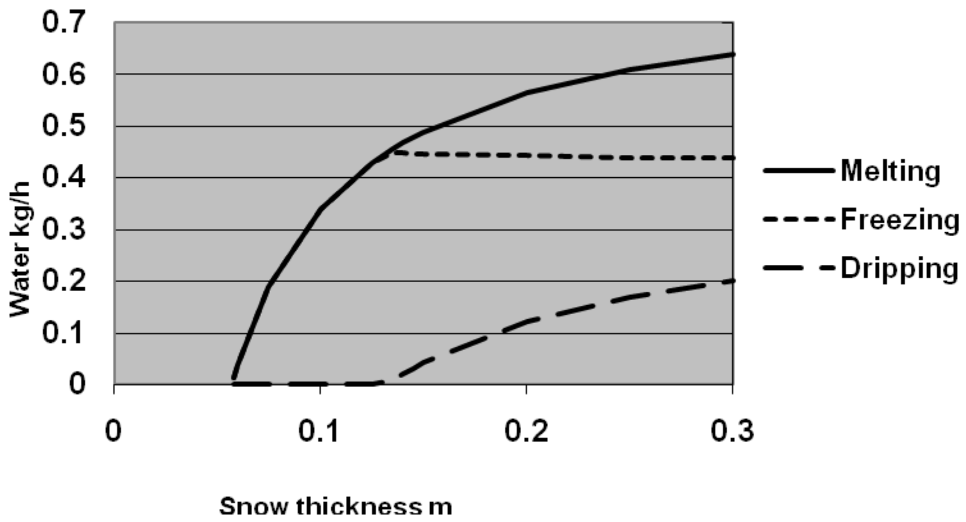

Figure 5. Calculated melting water from the 7 m roof with variations in snow thickness. The amount freezing on the overhang and the dripping at the eaves are shown.

Figure 6 shows the effect of variation in the indoor temperature. For indoor temperatures below 6 ^{o}C no water will melt and we get no problems with icicles. This is a well known fact in cold climates – keep the attic temperature low, then we will get less problems with icicles. If the indoor temperature is increased all the water will freeze on the overhang and first if we have a temperature above 17 ^{o}C the dripping begins.

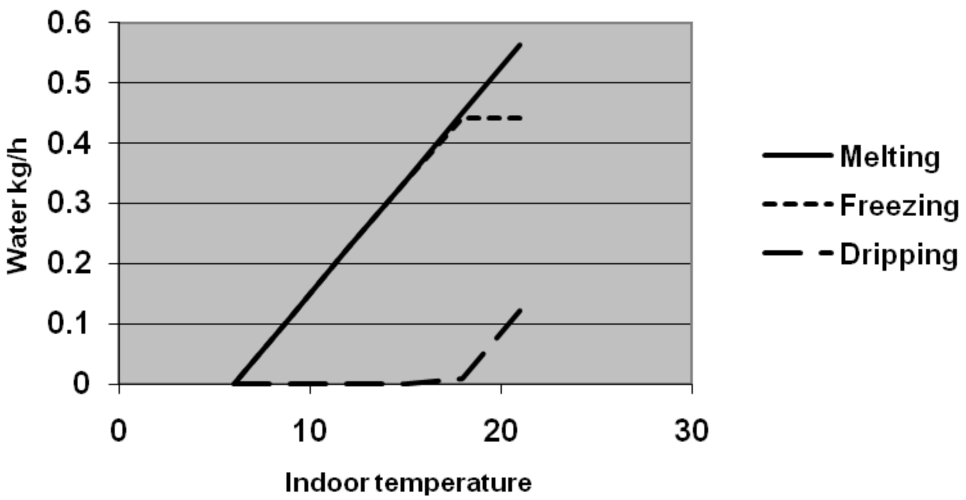

Figure 6. Calculated melting water from the 7 m roof with variations in indoor temperatures. The amount freezing on the overhang and the dripping at the eaves are shown.

Figure 7 shows the effect of variations in the U-value of the roof. For a good thermally insulated roof (low U-value) we have no melting. If the U-value of the roof increases the melting will increase. The freezing will increase until a maximum value dependent on the energy balance. The amount of water dripping will increase with an increase in the U-value.

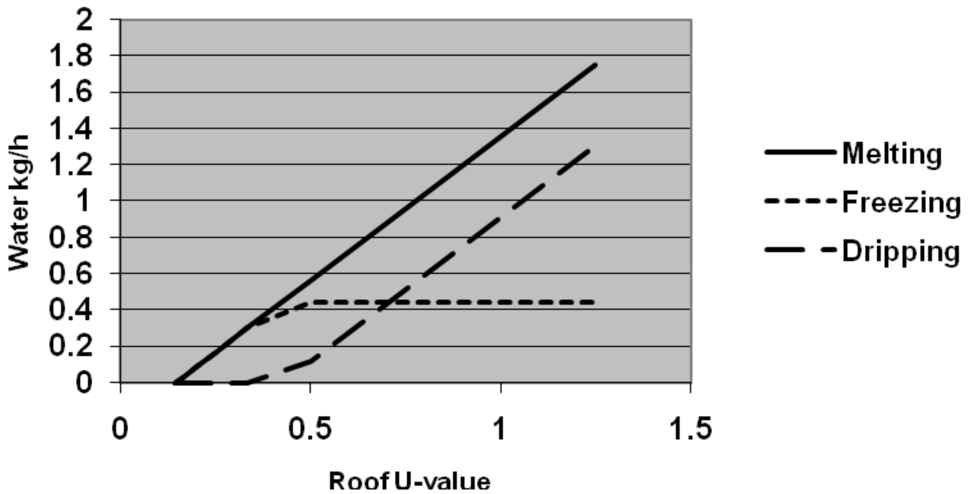

Figure 7. Calculated melting water from the 7 m roof with variations in the U-value of the roof. The amount freezing on the overhang and the dripping at the eaves are shown.

This calculation method can also be used for calculations of roof windows. They will typically have a higher U-value than the rest of the roof. The snow will melt on them and water will run down on the roof part below the window. The result is icing there. Melting water from the roof above the roof window will further increase the icing. The result is a high risk of ice dams that could cause a leakage in the lower part of the window. In practice the recommendation is to place roof windows at the top of the roof – this will reduce the risks. An alternative is not to use roof windows in areas with cold climate.

The calculations are based on stationary conditions and do not take into account that melting will reduce the thickness of the snow and that will again reduce the water melting flow. The freezing of ice on the lower part of the roof will also alter the energy balance. Result from such a non-stationary model will be presented in a later journal article. That study will also look at the effect of the typical daily variations in the outdoor temperature. This can give us a prediction tool for when icicles will be generated and when will they fall down.

ICICLES

Freezing of dripping water or melted snow forms icicles as in figure 1. The normal distance between newly formed icicles is around 2.5 cm (Nielsen, 2008). Icicles are found not only at roofs, but also in nature from trees, waterfalls, fences and so on. The form on the icicles is shaped as a cone or more correctly as a carrot form (Nielsen, 2008) with the thick end at the top. The source of the icicles is liquid water, so we need to have temperatures above the freezing of the water to generate the icicles. A water source at the root of the icicle will make a liquid film on the surface of the icicles that will cover the entire icicle if the flux of water is not very small. The thickness of the liquid film is 40-100 μm. To get the icicle to grow the air temperature must be below 0 ^{o}C. When the icicle grows the latent heat from freezing must be taken from the ice-water interface. The heat loss rate from the surface to the surrounding will control the growth rate of the icicle. In cold temperatures, the freezing will go faster but also the humidity, wind speed and solar radiation is important. The heat loss from the surface to the air is mainly by thermal convection and by evaporation. This is described in detail in Nielsen (2005). Radiation to the surrounding is of minor importance and heat conduction in the interior of the icicle is negligible. When the water flow down the surface of the icicle part of it will freeze. However, if the water supply is large enough a water drop will be formed at the end of the icicles. This drop grows until it reached a certain size around 5 mm in diameter and then falls and a new drop will be formed.

A PRACTICAL CASE – ICING ON A LARGE ROOF

In the winter 1987, The Norwegian Building Research Institute got information on icing problems on a large roof as described in (Juul and Böhlerengen, 1990). The roof had a U-value of 0.25 W/m^2K, a length of 16 meter and a slope of 20 degrees. The roof surface was metal. The roof was made as ventilated roof with an air gap of 48 mm. The size of the icicles was very large from 2 to 4 m from the roof to the ground. The heat loss though the roof should not be able to melt so much snow if the indoor temperature is 20 ^oC. An inspection on the site and later discussions with the manager of the heating system showed, that the technical installation room below the roof had a temperature of up to 40 ^oC in the winter. The warm air was also blown in under the roof with a temperature above 20 ^oC. The conclusion was that the high temperature under the roof would melt much of the snow on the roof. The ventilation gap was also too small to get an air temperature in the gap around 0 ^oC. Theoretical calculations by Nielsen found in the report showed that the air gap should be 15 cm in a roof with 16 m length. The solution was first to increase the insulation of the technical room so the heat loss was reduced and increase the size of the ventilation air gap in the roof. In this case the icicles were placed so that the risk for personal damage was minimal.

HEATER CABLES AND SNOW GUARDS

Use of electric heater cables is necessary in some cases to be sure that the melting water can run of without freezing. This will reduce the risk of generation of icicles. Typical use is for cold ventilated roof with external gutters. The cables are placed in gutters and downpipes. In some cases we will still get icicles, as the heat effect is too low or the cables have been moved by snow and ice so the effect is reduced in certain areas. Design rules for gutter systems and glass roofs are found in (Hugdal and Nielsen, 1991). In that case the problem is more sliding of snow from the sloped glass as the snow will slide when melting is starting in the bottom of the snow layer. The result is reduced snow load on glass roofs and that is now part of the international standard for snow loads on buildings. The electricity cost of using the heater cables can be very high, if you do not have some kind of control system to turn of the heat off when it is not needed.

To avoid snow slides or that ice formed at the eaves fall down it is normal to have snow guards on roofs (Byggforsk A525.931, 1996). The slide happens when the snow melts on the underside of the snow layer. This happens if either the outdoor temperature is above 0 ^oC or we have heat loss from the building or solar radiation. The roof slope and the roofing material determine if snow guards must be used. Metal roof is an example of a roof type where snow guards are necessary. A problem with many snow guards is that they are not strong enough or the snow can slide above or under it. Snow and ice slides from the roof can also get icicles to fall down from the mechanical load of the sliding material. More about snow guards is found in the reference above. If the snow guards work then the problem will come from the melting of the snow and the risk of getting icicles on the roof.

PROBLEM AREAS AND CONCLUSIONS

If we look at practical cases we can get ice and icicles along the gutter at the roof eaves as seen in figure 1. This will happen with overhanging eaves, which is cold because there is no warm building below. Here the melting water will freeze. But certain details have a higher risk, typically at the downpipes because they freeze and then we get melting water freezing at the top. Another typical problem area is the valley between two roofs, especially at the base.

Valleys are a difficult area to ventilate and we also have more melting water in this area. This gives a high risk of icicles. Small gables can be placed on the roof above the doors to prevent icicles. The problems are that we now move the problem to the valleys between the gable and roof.

Roof windows can also be a problem in areas with much snow. The snow will melt on the window and then the water will freeze on the insulated roof below. In areas with much snow in the winter the rule of thumb is not to use roof windows but make an attic with a vertical window.

As always these guidelines will depend on the type of the building, the geometry, the construction and the technical insulation, so some points are more important than other in a real case. We expect to continue work in this area and present a model as assistance in the evaluation of the risk for melting, freezing and generation and downfall of icicles. We know that in some winters we do have many periods with icicles and in others few. It depends on the local climate. The Swedish Meteorological and Hydrological Institute SMHI should be able to predict weather periods with risk for icicles generation as it is done for winter road conditions.

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