Snow melting and freezing on older townhouses

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KEYWORDS: *Snow, Melting, Roof, Icicles, Townhouses, Risk*

SUMMARY:

The snowy winter of 2009/2010 in Scandinavia prompted many newspaper articles on icicles falling from buildings and the risk this presented for people walking below. The problem starts with snow melting on the roof due to heat loss from the building. Melt water runs down the roof and some of it will freeze on the overhang. The rest of the water will either run off or freeze in gutters and downpipes or turn into icicles. This paper describes use of a model for the melting and freezing of snow on roofs. Important parameters are roof length, overhang length, heat resistance of roof and overhang, outdoor and indoor temperature, snow thickness and thermal conductivity. If the snow thickness is above a specific limit value – the snow melting limit- some of the snow will melt. Another interesting limit value is the dripping limit. All the melt water will freeze on the overhang, if the snow thickness is between the two limit values. Only if the snow thickness is above the dripping limit, will we get icicles. The model is used on an old townhouse without much thermal insulation and compared with newer townhouses. A discussion on attic temperatures is included. The results show that better thermal insulation or ventilation with outdoor air is the best way to reduce the risk of icicles.

1. Introduction

FIG 1. Icicles hanging from a building with large overhang

In winter snow will accumulate on the roof of buildings. Part of the snow melts and the water flow could generate icicles at the eaves, as seen in Figure 1. This occurs if there is solar radiation on the roof, as it will melt part of the snow. But this is not the most important factor. Investigations in United States (Tobiasson et al. 1998) showed that the most important factor for the generation of icicles is melting caused by a heated building. The problem is smaller for a thermally well-insulated building. An unheated building presents few problems. The building in Figure 1 has many icicles, but the risk is low as people cannot walk in the area below. For many townhouses icicles are a serious problem as they can fall on people and in the worst case kill them. Practical information for house owners are found in two Swedish reports: (Se upp där nere) and (Snö och is på tak 2004). A Canadian report (Straube 2006) discusses formation of ice dams on the roof. Growth and generation of icicles are described in more detail in Nielsen (2005) and (2008).

2. Energy balance – calculation method

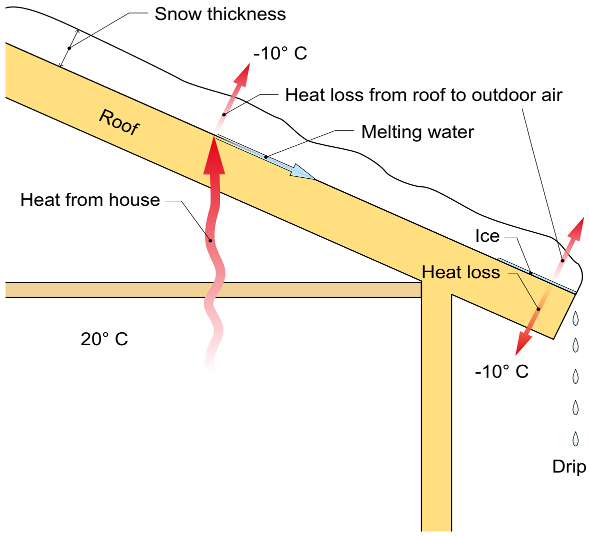

FIG 2. Drawing of the heat flow and water flow on the roof

The calculation method is described in (Claesson and Nielsen 2011). The report includes models for calculation of roofs with roof windows (skylights). They will always give more melt water and a higher risk of icicles. This paper describes the results from the method used on normal roofs. Figure 2 is a sketch of the energy and water balance of a typical roof. We assume that the attic is not ventilated. The effect of a ventilated attic and air leakages from the inside is discussed later in Example 3.4. The heat flows from the interior of the house to the surface of the roof through the roof construction. The heat will flow through the snow to the outdoor air and possibly melt some of the snow. With small snow thicknesses there will be no melting of the snow as the surface temperature on the roof is below 0^oC. With large snow thicknesses the bottom of the snow layer will melt and result in melt water that follows the slope of the roof. It is therefore interesting to calculate the snow thickness that is the limit between melting and no melting. This is the case if the roof surface temperature is 0^oC. This is called the melting limit. With known indoor and outdoor temperatures as well as the U-value of the roof, the snow melting thickness can be found. The results are given in Figure 3 for four house types:

An old poorly insulated house with a roof U-value of 1 W/m^2K
An insulated house with a roof U-value of 0.3 W/m^2K
A new house with a roof U-value of 0.15 W/m^2K
A future house with a roof U-value of 0.1 W/m^2K

As an example we chose an old house and an outdoor temperature of -15^oC. The snow melting limit becomes 4.5 cm. If more than 4.5 cm snow falls on the roof, then there will cause melt water and a risk of icicles. With -15^oC outdoors there is a high risk that most of the melt water will generate icicles. If the house had been insulated, then the limit would have been 15 cm. The conclusion is that it will always be a good idea to insulate the house, as it reduces the risk of icicles.

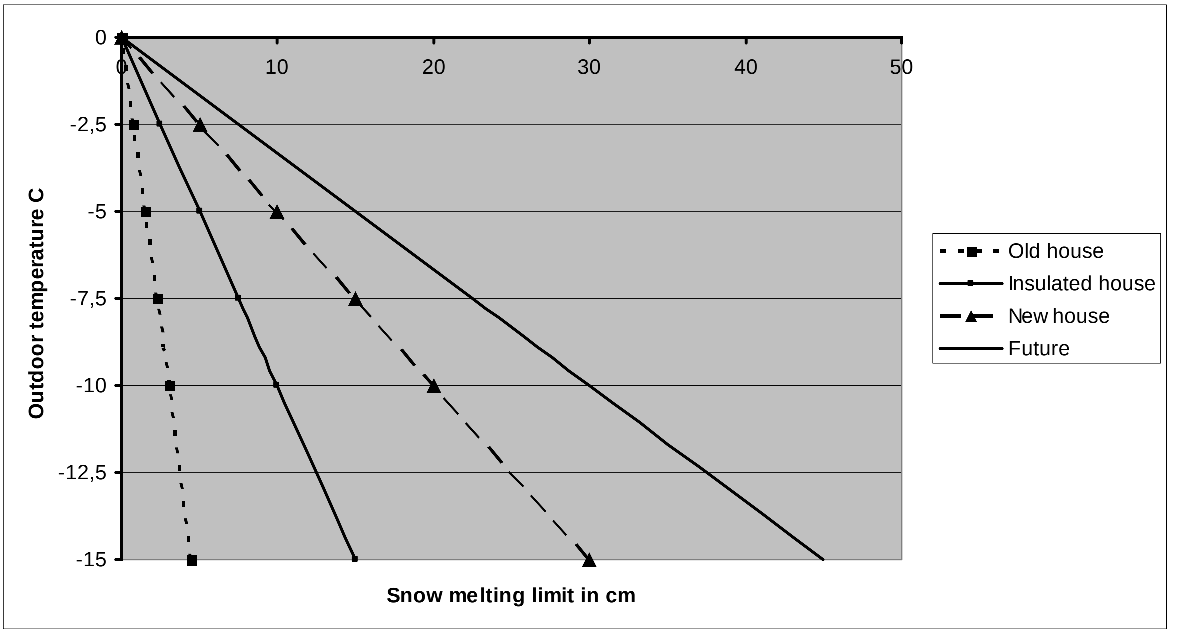

FIG 3. Snow melting limits for 20^{o}C indoor temperature and different house types and varying outdoor temperatures

If the roof has an overhang, then the temperature both above and below the overhang is the outdoor temperature. The result is that melt water from the upper part of the roof can freeze on the overhang. The result is a layer of ice on the overhang. If the flow of the melt water is low, then all the melt water freezes on the overhang. With stronger flows part of the melt water drips from the eaves and icicles can form. The dripping limit is the snow thickness where all the melt water freezes over the full length of the overhang. The dripping limit will always be higher than the snow melting limit, as seen in Figure 4.

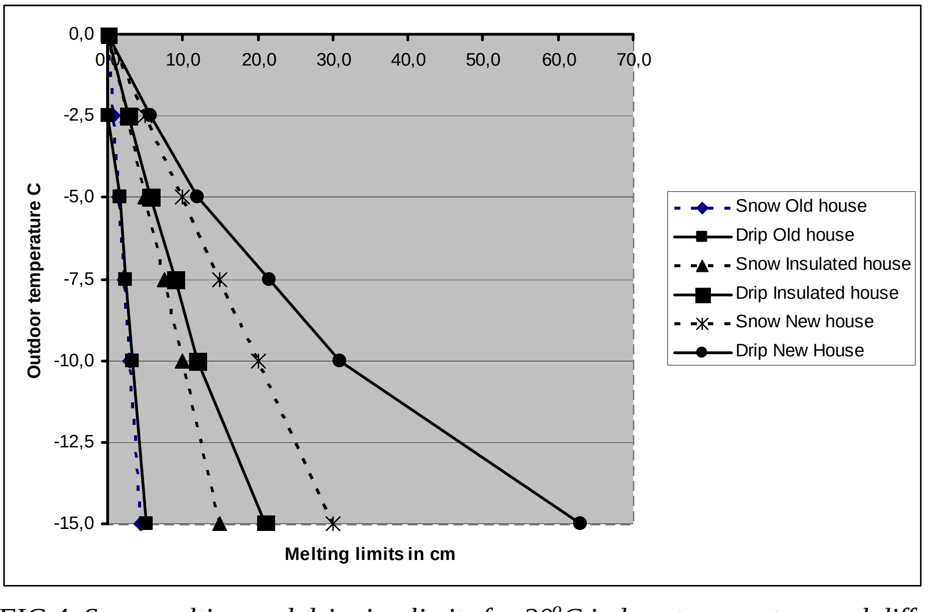

FIG 4. Snow melting and dripping limits for 20^{o}C indoor temperature and different house types and outdoor temperatures

In Figure 4 we have the snow melting limits (dotted lines) and dripping limits (full lines) for 3 houses. It is seen that for an old house the dripping limit is nearly the same as the snow melting limit. For a new insulated house the dripping line is much higher than the melting limit, as a larger part of the melt water will freeze on the overhang. The result is that a well-insulated house has a lower risk of icicles.

3. Examples and basis for calculations

There is a major difference between the problems of single family houses and those of townhouses. Most single family houses are placed in the centre of a plot, so that icicles and sliding snow only affect the area immediately surrounding the house. It is mostly here that occupants can be affected. In most cases they will know were the problems are and can remove icicles hanging for instance over the front door. Townhouses are typically placed at the perimeter of the plot, so that snow and ice can fall on the pedestrian area along the building. In many cases icicles cannot be removed without using a crane or ladders. An increased risk comes from icicles falling several storeys. It is the building owner's responsibility to remove icicles. The following examples show calculations of the snow melting on the roof. Part of this water will freeze on the overhang – so having an overhang reduces the risk. The resulting water can drip at the eaves and either flow into the gutter, down the downpipes or generate icicles. If there is no heat cable in the gutters, the water in the gutter freezes rather fast resulting in more melt water, which can generate icicles. The amount of icicles will depend on the local conditions at the eaves and gutter as described (Nielsen 2005). Reducing the dripping water will reduce the risk of icicles.

The calculations in the following examples are based on these assumptions. The snow density is 200 kg/m^3 with a thermal conductivity of 0.06 W/mK. This is a reasonable estimate as new snow has a lower density and old snow a higher density. The following parameters must also be known. The indoor temperature (typically for a heated house 20^{o}C) and the outdoor temperature (must be below 0^{o}C for icicles to form). The length of the roof from the ridge to the outer wall is given. The length of the overhang from the wall to the eave (gutter) is given. The thermal insulation of the roof and the overhang is given as U-values. The calculation is performed for a width of the roof of 1 m. If there are airspaces or open attics, it is assumed that they are unventilated. The effect of a ventilated attic is discussed in Example 3.4. Other calculation cases with variation in roof length overhang length and other parameters are found in (Nielsen and Claesson 2009).

3.1 Old house with nearly no thermal insulation in the roof

This is an example of a typical older townhouse built before 1950 with scarcely no thermal insulation, a building width of 13 m and a roof slope of 30-45 degrees. The slope faces the street. The calculation applies these data: Roof length is 8 m and the overhang is 40 cm. The U-value of the roof is 1.0 W/m^{2}K. The U-value of the overhang is 2 W/m^{2}K. The indoor temperature is 20^{o}C and the outdoor temperature is -10^{o}C. After a snowfall of 20 cm, the snow on the roof will start to melt and the reduction of the snow thickness is seen in Figure 5 and in Table 1. As seen in Figure 5, it takes 300 hours before the snow is in equilibrium and the melting stops.

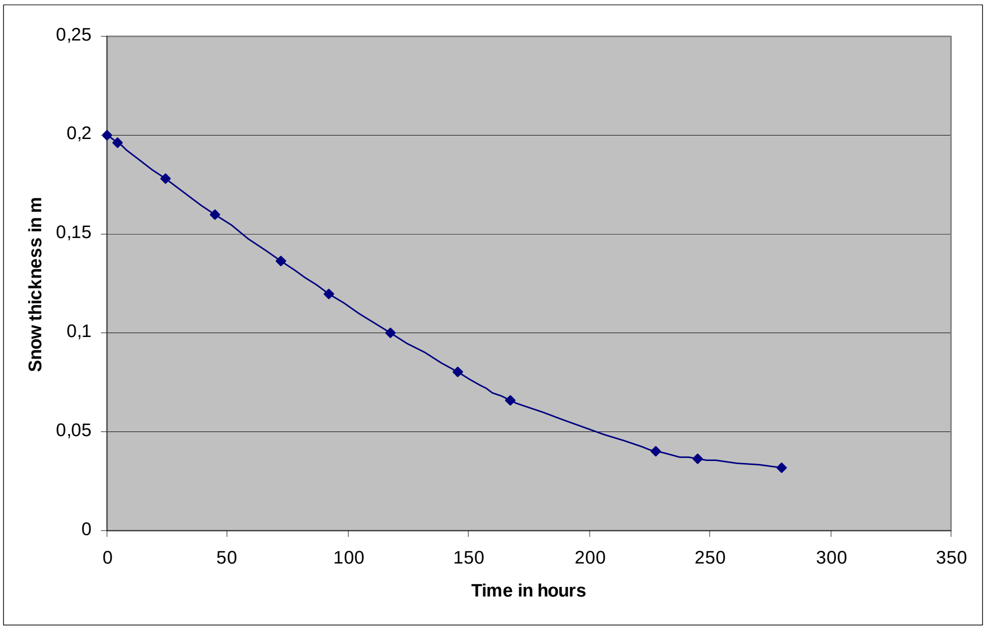

FIG 5. The change in snow thickness with time for an old uninsulated house

TABLE 1. Snow balance on an old house roof depending on time

Time hours	Thickness snow cm	Melted snow kg	Ice on overhang kg	Water drips Kg
0	20	0	0	0
24 (1 day)	17.8	35	2.4	33
72 (3 day)	13.6	102	7.1	95
168 (7 day)	6.6	214	16.6	198

The snow thickness will be reduced by 2.2 cm during the first day and by 13.4 cm in a week. The last three columns in Table 12 show total melted snow, ice on overhand and dripping. It is seen that less than 10% of the melted snow freezes on the overhang. The ice on the overhang increases the load on the overhang. The water drip will either be running through the gutter and down the drain or generate icicles. This type of roof has a very high risk of icicles. The risk is up to 33 kg icicles per day.

TABLE 2. Snow balance on an old house roof for different snow falls (initial values time 0)

Snow layer	Melt water kg/day	Freezing kg/day	Dripping kg/day
20 cm	35.1	2.4	32.7
10 cm	28.9	2.7	26.2

Table 2 lists the water balance for a 20 cm or 10 cm snow fall (calculated for the first day). In both cases are the dripping rate high and the risk of icicles high. The calculated melting limit for this roof and thermal conditions is 3 cm. The snow does not melt until there is 3 cm snow on the roof. If the snowfall is less than 3 cm, the snow will not melt.

TABLE 3. Snow balance on an old house for varying outdoor temperatures after a 20 cm snow fall

Outdoor temperature	Melt water kg/day	Freezing kg/day	Dripping kg/day
-5^{o}C	38.2	1.2	37.0
-10^{o}C	35.1	2.4	32.7
-15^{o}C	32.0	3.6	28.4

Table 3 shows the snow and water balance for varying outdoor temperatures for the first day. The melt water is reduced with lower outdoor temperatures, but at -30^{o}C it will still continue to drip.

For this type of house the best solution is to increase the thermal insulation in the roof for instance to the level of a U-value of 0.3 W/m^{2}K in the next example. This will reduce the risk of icicles.

3.2 Old house with around 10 cm thermal insulation in the roof

This is an example of a typical thermally insulated townhouse with a building width of 14 m and a roof slope of 20-35 degrees. The slope faces the street. The calculation applied these data: Roof length is 8 m and overhang is 40 cm. The U-value for the roof is 0.3 W/m^{2}K. The U-value for the overhang is 2 W/m2K. The indoor temperature is 20^{o}C and the outdoor temperature is -10^{o}C. After a snowfall of 20 cm, the snow on the roof will start to melt and the reduction of the snow thickness is given in Table 4.

TABLE 4. Snow balance on an old house roof depending on time

Time hours	Thickness snow cm	Melted snow Kg	Ice on overhang kg	Water drips Kg
0	20	0	0	0
24 (1 day)	19.6	6.1	3.7	2.4
72 (3 day)	18.9	18.0	7.1	10.9
168 (7 day)	17.4	41.2	17.0	24.2

The snow thickness will be reduced by 0.4 cm in the first day and 2.6 cm in a week. Compared with example 3.1, the melting is much reduced. The last 3 columns show total volume of melted snow, ice on overhand and dripping. It is seen that around 50% of the melted snow freezes on the overhang. The ice on the overhang increases the load on the overhang. The water drip amount will either be running through the gutter and down the drain or generate icicles. This type of roof has a much lower risk of icicles.

TABLE 5. Snow balance on an old house roof for different snow falls

Snow layer	Melt water kg/day	Freezing kg/day	Dripping kg/day
20 cm	6.2	2.4	3.8
10 cm	0.0	0.0	0.0

Table 5 shows the snow and water balance for a 20 cm and 10 cm snow fall. For a 20 cm snow fall the dripping rate are low and the risk of icicles too. The calculated melting limit for this roof and thermal conditions is 10 cm. So for a snow fall of 10 cm or less, the snow will not melt and no icicles form.

TABLE 6. Snow balance on an old house roof for varying outdoor temperatures after a 20 cm snow fall

Outdoor temperature	Melt water kg/day	Freezing kg/day	Dripping kg/day
-5^{o}C	9.3	1.2	8.1
-10^{o}C	6.2	2.4	3.8
-15^{o}C	3.1	3.1	0

Table 6 shows the snow and water balance for varying outdoor temperatures for the first day. The melting is reduced with lower temperatures. The dripping rate is high for higher temperatures, so the risk of icicles is higher. If the temperature is below -15^{o}C, there is no dripping.

3.3 New house with around 25 cm thermal insulation in the roof

This is an example of a typical new thermally insulated townhouse with a building width of 14 m and a roof slope of 20-35 degrees. The slope faces the street. The calculation applied these data: Roof length is 8 m and the overhang is 40 cm. The U-value for the roof is 0.15 W/m^2K. The U-value for the overhang is 2 W/m^2K. The indoor temperature is 20^oC and the outdoor temperature is -10^oC. After a snowfall of 20 cm or less, the snow on the roof will not melt. In this example the melting limit is 20 cm. If there is a snow thickness of less than 31 cm, there will not be any dripping as all the melting water freezes on the overhang. The dripping limit is 31 cm. An example of a 25 cm snow fall is given in Table 7.

TABLE 7. Snow balance on a new house roof depending on time after a 25 cm snow fall

Time hours	Thickness snow cm	Melted snow kg	Ice on overhang kg	Water drips kg
0	25	0	0	0
24 (1 day)	24.9	1.2	1.2	0
168 (7 day)	24.5	8.0	8.0	0

The snow thickness is reduced with 1 mm the first day and 5 mm in a week.

TABLE 8. Snow balance on a new house roof for varying outdoor temperatures after a 20 cm snow fall

Outdoor temperature	Melting water kg/day	Freezing kg/day	Dripping kg/day
-5^oC	3.1	1.2	1.9
-10^oC	0.0	0.0	0.0
-15^oC	0.0	0.0	0

Table 8 lists the snow and water balance for different outdoor temperatures for the first day. If the temperature is less then -10^oC, then there will be no dripping. If is colder than -8^oC, then there is no dripping as the water freezes on the overhang. This type of building rarely results in icicles as most of the snow will not melt before the air temperature reaches above 0^oC or there is solar radiation on the roof.

3.4 Old house with ventilated attic

This is an example of a typical older townhouse built before 1950 with scarcely no thermal insulation and a building width of 13 m and a roof slope of 30-45 degrees. The slope faces the street. It is assumed that the attic is ventilated. The airflow could come through air leakages from inside the building, if it is not airtight. This warm air will increase the attic temperature. An attic is also typically ventilated with outdoor air. This will reduce the attic temperature. In this case we assume that the attic temperature is known. The calculation applied these data: Roof length is 8 m and the overhang is 40 cm. The U-value for the roof above the attic is 2 W/m^2K. The U-value for the overhang is 2 W/m^2K. Table 9 gives the snow balance for varying attic temperatures after a snowfall of 20 cm.

TABLE 9. Snow balance on an old house for varying attic temperatures with -10^oC outdoor

Attic temperature	Melt water kg/day	Freezing kg/day	Dripping kg/day
0^oC	0.0	0.0	0.0
1.5^oC	0.0	0.0	0.0
2^oC	2.1	2.1	0
3^oC	6.2	2.4	3.8
5^oC	14.4	2.4	12.1
10^oC	35.1	2.4	32.7
20^oC	76.3	2.4	74.0

Table 9 shows that if the attic temperature is kept at 1.5^oC or lower, then there will be no melting as in (Tobiasson et al. 1998). The recommendation in that paper is to ventilate the attic so the temperature in the attic is kept below -2^oC during freezing periods. Temperatures in the attic depend on the energy balance. In Example 3.1 the melting is 35 kg/day and that is the same as for an attic temperature around 10^oC. For the two other examples the corresponding attic temperature is 3^oC and 1.5^oC. If there is a heat source like for instance heating pipes or a ventilation room in the attic space, then the attic temperature will rise and result in more dripping and a higher risk of icicles.

4. Conclusions

The calculation examples show that old townhouses have a high risk of developing icicles as the dripping rate is high. The amount of icicles can be reduces with better thermal insulation of the roof and this should be done in all cases, where it is possible. This is illustrated in the examples with newer houses. If the attic is ventilated, then it is important to know the winter temperature in the attic – if it is below -2^oC, then there is no melting. This temperature level can be reached with either better thermal insulation or increased ventilation with outdoor air. Heat sources in the attic such as heat pipes, ventilation ducts and ventilation systems must be insulated

The new and better insulated houses have a higher snow load as the snow melts slowly, so it is important to remember that this snow will either melt on the roof or slide down when is start to thaw. Snow guards can be a good solution for reducing the risk of snow sliding down on the pedestrian area. The gutters are important to drain away the dripping water from the melting snow. The solution can be larger gutters and/or heat cables (Hugdal and Nielsen 1991). We cannot expect to avoid icicles, but with these recommendations it is possible to reduce the amount of icicles hanging from roofs.

5. Acknowledgements

The research section in Länsförsäkringar, which is a Swedish banking and insurance alliance, supports the work.

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