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Moisture in Insulated Roofs with Load-bearing Steel Deck

Feuchtigkeit in isolierten Stahldächern

Humidité dans des toitures isolées contenant de la tôle profilée d'acier

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SUMMARY
The paper deals with some practical questions related to roofs and roofing such as moisture, water and melting snow, thermal insulation. Thermal bridges and/or a thick layer of snow can cause melting of the snow. Air transport through the roof and in the roof may cause moisture condensation on the cold surface. Mechanical fasteners need a "dry climate" in order not to corrode.

RÉSUMÉ
L'article traite des problèmes pratiques de toits concernant l'humidité, l'eau et la neige fondue, et l'isolation thermique. Des ponts thermiques et/ou une couche épaisse de neige peuvent provoquer la fonte de la neige. La ventilation dans le toit et à travers le toit peut causer une condensation sur la surface froide. Des attaches mécaniques ont besoin d'un climat sec pour éviter la corrosion.

ZUSAMMENFASSUNG
Einige praktische Probleme mit dem isolierten Stahldach werden beschrieben. Sie betreffen Feuchtigkeit, Isolation, Wasser und schmelzenden Schnee. Schneeschmelze wird bisweilen von Kältebrücken verursacht, aber häufiger von einer dicken Schneeschicht. Lufttransport im Dach und durch das Dach kann Kondensation unter der kalten Oberfläche verursachen. Mechanische Verbindungsmittel brauchen jedoch ein "trockenes Klima", um nicht zu korrodieren.

1. INTRODUCTION

An externally insulated steel deck consists of a load-bearing trapezoidal steel sheet, sometimes a plastic sheeting, thermal insulation and a water proofing layer of roofing felt, a single-ply membrane or steel sheets. Two types are shown in fig.1. The type of roof is very often used in industrial buildings, in schools, in supermarkets etc. Rather thick thermal insulation is used in the roof. This has lead to lower temperature in the waterproofing membrane, which means that the surface will be exposed to larger temperature variations than with a low insulation thickness. This influence may lead to ice cracks in the membrane. To avoid this the membrane must have good flexibility (elastic properties) even at very low temperature and a high elongation at rupture.

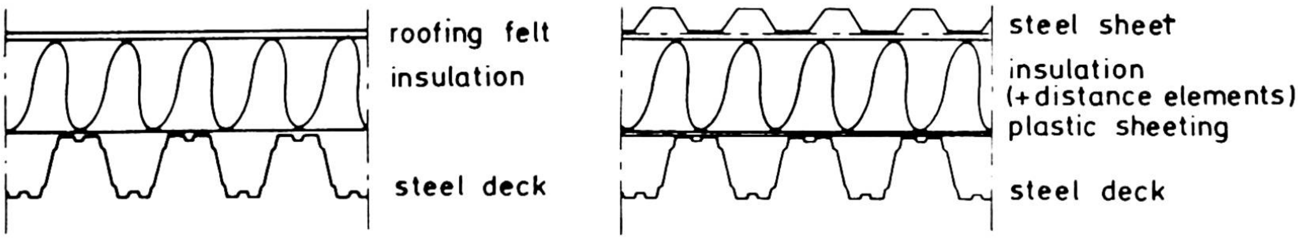

Fig. 1 Two types of insulated steel decks.

2. MOISTRUE

There are several ways for moisture infiltration into the roof. Moisture can be built in during rainy or snowy days. It can get there through leaks in the waterproofing membrane. It can come from the inside of the building through diffusion or convection. Moisture in the structure must have the possibility to disappear from the roof, which means that only one water/air/moisture proof layer is needed. The design with roofing felt on the top and a vapour barrier between the steel deck in the insulation may act as a "moisture trap", fig. 2. Once moisture has entered into such a roof it has to stay there. Diffusion is usually not a problem for the common steel deck and the water built-in usually disappears during the first summer period.

In certain cases convection may cause trouble. If you blow hot humid indoor air into the roof you will get problems. The amount of moisture transported through convection is proportional to the difference in air pressure between the indoor and outdoor air. The steel sheet is airtight - but the splices are not. However, the steel sheet is very often perforated for acoustic reasons and this totally destroys the possibility for the steel deck to prevent the air to enter into the structure.

If, on the other hand, there is no airtight exterior layer, an airtight plastic membrane, "vapour barrier", must be added to the structure, placed between the insulation and the steel deck, cf. fig. 1, or in the insulation placed between two layers of insulation. The plastic membrane is not perfectly tight due to screw penetrations or due to the side overlaps. Measurements show a low amount of air-leak. For a screwhole with remaining screw an air leakage of 0.003 m^3/h has been measured at a pressure difference of 50 Pa. This corresponds to 17 g water during one month if the indoor air has a temperature of 20°C and a 50% relative humidity. When the screw is removed from the hole the air leakage is 0.09 m^3/h per hole, which corresponds to 0.56 kg water per month. The leakage measurements are taken at very high level of the pressure difference. Wind speed and temperature differences may cause 10-20 Pa pressure difference, which is a more realistic level over a longer period of time. With a linear relationship between air leakage and air pressure we only get 5 g moisture per month for each screw.

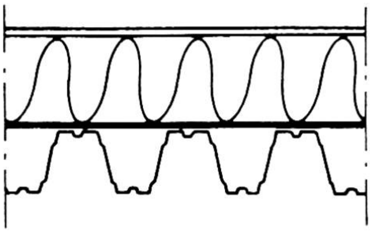

Fig. 2 Steel deck with two airtight membranes may act as a "moisture trap".

Theoretically and in laboratory tests, but probably not in practice, it is possible to use the steel sheet as an air barrier. Table 1 shows some results from air leakage tests on splices in steel sheet. The sheet was an ordinary trapezoidal steel sheet, 45 mm deep and 0.7 mm thick. The side overlap was riveted with pressure-tight pop rivets. Tests were also conducted with a tightness strip installed in the overlap. The length of the leakage way is 100 mm. The amount of air passing through the joint with the tightness strip is very low. The result is much better than what is usually reached when testing ordinary overlap splices in plastic sheeting.

Humid indoor climate combined with overpressure ventilation may in certain cases lead to problems with condensation in the roof if there is some air leakage through the inner surface. However, "condensation" seems to have become some kind of a general explanation for dripping water, when the leaks are not found after a short and incomplete inspection of the roof.

Table 1 Measured air leakage through pop riveted splices in steel sheet.

Distance between rivets m	Leaking air (m^3/hm) at the pressure difference 10 Pa	40 Pa
0.6	0.14	0.51
0.3	0.17	0.58
0.15	0.15	0.56
0.3 (with tightness strip)	0.01	0.04

3. MOISTURE FROM THE OUTSIDE

Sometimes ventilation air coming from the outside may be very dangerous. For a roof with a principal design shown in fig.3 the ventilation air is passing via the space between the upper steel sheet and the thermal insulation. Due to the low temperature of the steel sheet - the roof surface may be 10° C colder than the surrounding outdoor air - the ventilation air will be cooled down. This may lead to condensation in the roof if the temperature is low enough to give 100% relative humidity in the ventilation air. Table 2 shows temperature and humidity measurements for a roof similar to fig.3. The measurements were taken during a clear winter night at different points in the building. There was no snow on the roof.

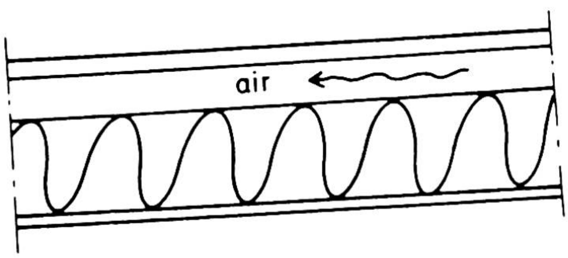

Fig.3 A roof with ventilation air under the exterior steel sheet.

Table 2 Measured temperature and relative humidity for a roof with ventilated exterior steel sheet.

	Temperature °C	Relative humidity %	Moisture content g/m³
Inside the building, near the floor	14.9	24	3.1
Inside the building, near the roof	17.0	25	3.6
In the roof air space, 6 m from intake	-8.0	80	2.0
Cutside	-5.0	87	2.8

The results show that both the air tgemperature and the moisture content are lower in the roof than outside. Under certain climatic conditions parts of the roof will act as a giant air dehumidifier. This shows that if there is some moisture in the roof it is not always possible to eliminate it with the aid of ventilation. By increasing the ventilation we may make the situation worse instead of solving the problem.

4. THE VAPOUR BARRIER AND MECHANICAL FASTENERS

In 1974 in situ investigations of the wind uplift strength of 29 industrial roofs were conducted |1|. All the roofs consisted of a steel deck and thermal insulation (mostly mineral wool) with thickness varying between 40 and 120 mm. On the top there was a bituminous roofing felt. None of the roofs had any type of vapour barrier between the steel deck and the insulation. In 1969 16 of the storm damaged roofs, of the same typ as mentioned above, were investigated |3|. Only one of the 16 roofs had a vapour barrier between the steel deck and the insulation. The use of a vapour barrier was not common for such roofs at that time (only one roof out of 45, i.e. 2%). The insulation and the roofing felt were glued with hot asphalt - no mechanical fasteners were used.

After the heavy storm damages in 1969 a new design philosophy started to grow, and after some years many of the industrial roofs were mechanically fastened with screws and washers. In the beginning the washer was placed directly on the insulation, under the roofing felt. After some blow offs the washers were applied after the first layer of roofing felt had been glued to the insulation. Since then there have not been any problems with blow offs if the work was carried out properly and if the design was correct. Some years after the introduction of mechanical fasteners the risk of corrosion on the fastener became a question of interest. Therfore, in 1979-1980 the fasteners on 14 different roofs (steel deck, insulation, roofing felt) were investigated by J Hellgren and B Johansson |2|. The oldest roofs that could be found were selected - the oldest roof investigated was eight years old and without any signs of corrosion. A total of 134 screws + washers have been removed and examined. The average age of the roofs was 5 years. Some little rust was found on 5% of the examined screws, but no serious corrosion was found. In Norway a similar investigation has been made in 1985 |4|. Forty-eight roofs have been examined, conrete, wood and steel roofs. The steel deck roofs can be separated into two types, roofs with and without vapour barrier respectively. The roofs with a vapour barrier show rust on the screw or washer in eight roofs out of nine. On the other hand, the roofs without a vapour barrier show red rust for one single screw on nine roofs.

These two investigations show that omitting the vapour barrier will not ruin the roof if there is an airtight membrane (roofing felt, PVC, EDM etc) as a top layer. Instead, the vapour barrier may be destructive for the roof. Usually there is no need for a vapour barrier if there is a roofing felt on the top. This type of roof has behaved well for a long time.

5. SNOW ON THE ROOF

During the winter time, when there is snow on the roof, we sometimes get a zone of melting snow close to the roof membrane. Some engineers - and that is not just a few - believe that the melting snow is caused by thermal bridges through the roof insulation. This may sometimes be the right explanation but more commonly the explanation is much simpler. The snow on the roof functions as an additional exterior thermal insulation. The snow temperature can never exceed 0°C which limits the effect of its thermal insulation properties. Due to the insulation effect of snow the zero temperature zone will be in the snow layer under certain circumstances. As long as the temperature on the top of the roof is 0°C the heat flow through the roof is constant.

For a roof consisting of a load-bearing steel deck, thermal insulation, water proofing membrane and a layer of snow, the temperature between the membrane and the layer of snow can be expressed as

$$\theta = \theta_e + \frac{R_{s,e} + d_{snow}/\lambda_{snow}}{R_{s,e} + R_{s,i} + R + \frac{d_{snow}}{\lambda_{snow}}} (\theta_i - \theta_e) \qquad (1)$$

where

θ = temperature at the membrane
θ_e = exterior temperature
θ_i = interior temperature
$R_{s,e}$ = thermal resistance for the exterior surface (0.04 m^2 °C/W)
$R_{s,i}$ = thermal resistance for the interior surface (0.13 m^2 °C/W)
λ_{snow} = thermal conductivity for snow
R = thermal resistance
d_{snow} = snow thickness

The snow on the roof will start to melt when the temperature θ at the membrane equals zero. From equation (1) we obtain the minimum snow depth at which the snow-melting starts.

$$d_{snow}/\lambda_{snow} = R_{s,e} + (R + R_{s,i})(-\theta_e)/\theta_i \qquad (2)$$

In the diagram, fig. 4, relationships between temperature and snow depth are given for different values of the thermal conductivity for snow. The example in fig. 4 consists of 200 mm mineral wool with λ = 0.040 W/m °C and the temperature indoor is 20 °C. The relationship between the thermal conductivities for snow used in the diagram and the density of snow are approximately

λ_{snow} (W/m °C)	: 0.05	0.10	0.20
density (kg/m^3)	: 100	200	300

The density 100 kg/m^3 corresponds to new powder snow and the density 300 kg/m^3 is used in different codes to determine the snow load on the roof. From fig. 4 it can be seen that new powder snow very soon starts to melt. If the outside temperature is -3 ° C the snow will start melting at 40 mm thickness. The older snow with 300 kg/m^3 density will start melting at 260 mm snow depth if the outside air temperature is -5°C.

The melting snow due to thermal insulation properties of the snow may explain many odd things, e.g. why water is dripping from the roof although the temperature is pretty much below the freezing point, why there nearly always is a layer of ice between the layer of snow and the membrane, why water sometimes enters into the structure even when it is cold outside. Melting snow on the roof is a quite normal physical phenomenon and it does not necessary indicate any faults in the design. As there is a temperature variation between day and night there will be periods of melting and freezing. This may have a bad influence on the water-proofing membrane, perhaps with cracks and water leaks. Mechanical fasteners act as thermal bridges and contribute to the melting of the snow. This may be seen in frosty autumn mornings. The energy transport through the fasteners is very small. One screw (Ø = 4 mm) per m^2 only gives an increase of the U-value of approximately 0.003 W/m^2 °C. The interior temperature and the

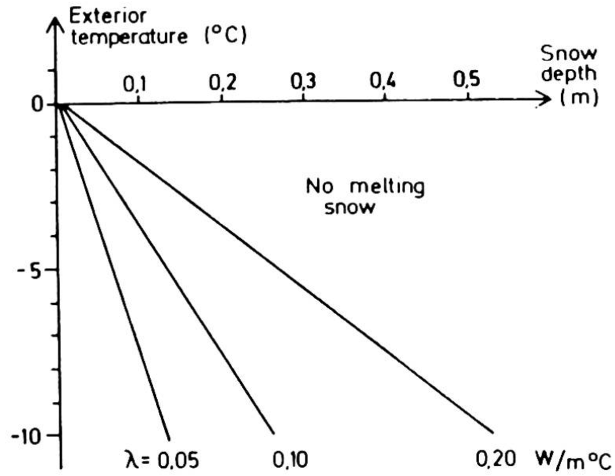

Fig. 4 Relationship between exterior temperature and snowdepth on a roof with R = 0.2/0.004 = 5 m^2 °C/W. Interior temperature is 20°C.

thermal resistance of the roof limits the amount of energy transportation through the roof. In order to melt one kg ice $334 \cdot 10^3$ Ws is required. With a thermal resistance of 5.13 m^2 °C/W and a 20°C difference in temperature it takes 23.8 hours to melt 1 kg snow. With a snow density of 200 kg/m^3, 5 mm depth corresponds to 1 kg/m^2. With the presumptions used it takes about three weeks to melt 100 mm snow. Some of the water in the melting zone will run away and some will remain in the snow on the roof. It is this blend of water and melting snow that may leak through or create problems for the membrane if the temperature falls.

6. CONCLUSIONS

Make the membrane ductile enough to withstand ice on the roof - then, together with good workmanship, the risk of leaking water is minimised.

Don´t force humid indoor air into the roof - don´t use overpressure ventilation, use underpressure ventilation instead. The vapour barrier may be punched through and in that case over pressure ventilation is not suitable. Increased ventilation in the roof may not be the solution of a moisture problem; instead it may make it worse. It all depends on the physical causes.

REFERENCES

1. GULLBRANDSON B. - JOHANSSON G., Field investigation of externally insulated sheeting roofs. Document D15:1978. Swedish Council for Building research.

2. HELLGREN J. - JOHANSSON B., Field tests of mechanical fasteners in externally insulated steel decks. (In Swedish). Int. paper S80:1. Division Steel and Timber Structures. Chalmers Univ of Technology, Göteborg 1980.

3. JOHANSSON G., Storm damage in Western Sweden. (In Swedish). Report R33:1970 Swedish Council for Building research.

4. PAULSEN E., Roofing fasteners. Report 21. Norwegian Building Research Institute, Trondheim 1987.