

TALAT Lecture 2104.01

Construction Product - Glass Roof

Roof Made of Glass and Aluminium

21 pages, 23 figures

Basic Level

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Objectives:

- To provide the teacher and students with a basis to develop sound and appropriate glass and aluminium roof designs.
- To learn to understand the principles behind good design.

After working through the course, the students will be in a position to design a glass roof which meets the requirements of local building regulations, and which is suited to the national traditions of the destination markets. This includes the collection of data on the local climate, because the product needs to withstand the climatic conditions in the different regions of the market. Safety and functionality are also important parameters of the finished product.

Prerequisites:

- basic design engineering background
- basic knowledge of corrosion effects
- TALAT lecture series 2100, 2200 and 5104

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2104.01 Construction Product - Glass Roof

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Effects of Climate

The most significant climatic factors relating to glass roofs are as follows:

- Driving rain
- Wind stresses
- Snow loads
- Overheating due to sun

Driving Rain

Rain in particular falling on a roof structure which is not impermeable may cause damage to the adjacent walls as well as the interior. Of course, the climate varies in the different regions of Europe, but generally speaking, it rains everywhere and the roof should act as a collector of rain wherever it is located. Water flows over all the joints, attempting to find leaks in the outer seal and so penetrate further into the section system itself. If after some time, the watertight properties of the outer seal are reduced, due to the effect of UV radiation and temperature fluctuations, the design must include a drainage system to collect the water which has penetrated and lead it outside, without

causing any leakage to the inside. This will be dealt with in more detail in a later chapter.

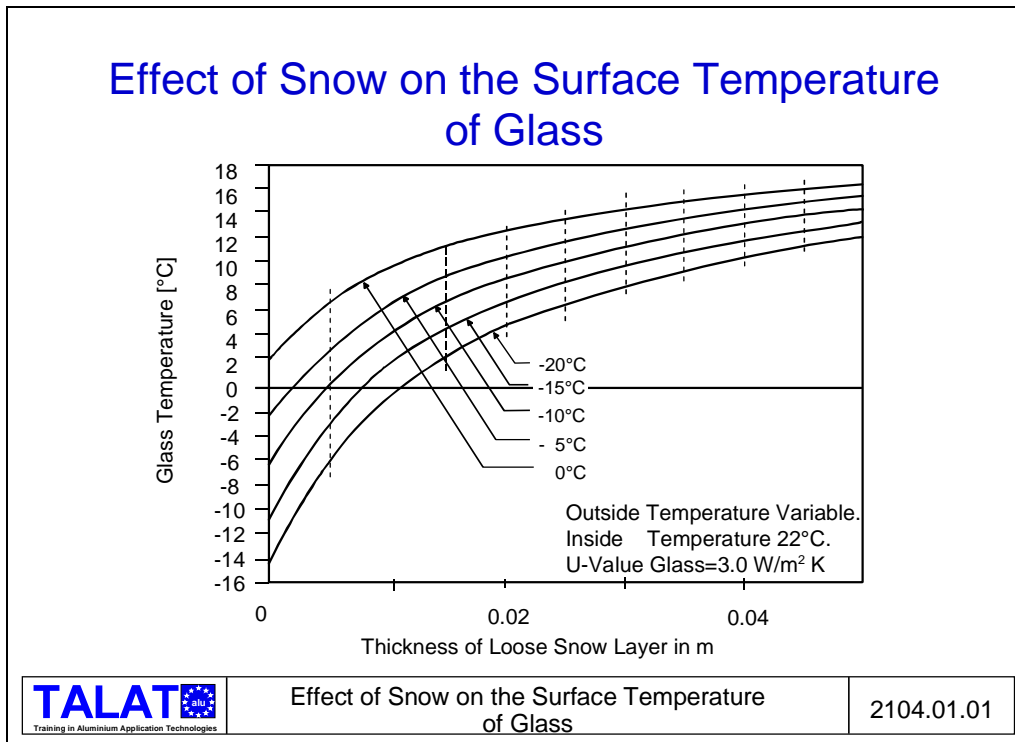
Wind Stresses

Wind stresses, in the form of suction affecting parts of the glass roof, may have unpredictable effects in extreme wind conditions. The local building authorities always provide details of the dimensions of the supporting system and the spans suitable for the normal wind conditions in that region.

Snow Loads

Snow loads, where applicable, vary considerably according to the location of the structure in the terrain, to the normal amounts of snow in the region, to the temperature conditions of the region, to the type of glass selected and to the heating of the conservatory. In areas which are exposed to wind, snow will rarely rest on the glass - it is blown off at once. During particularly heavy and concentrated snow falls, even just a few cms of snow on the glass have enough of an insulating effect to bring the surface of the glass up to 0 degrees, and the snow will start to slide off the roof (**Figure 2104.01.01**). Of course, we are assuming that the area under the glass roof is heated to the normal temperature for a living room, and that the snow does not come across obstacles in the structure which obstruct the normal process of sliding off. As the snow slides off and collects at the bottom of the roof, especially in the case of larger roof surfaces, it is necessary to keep that area particularly warm using heating cables, to cause the snow to melt as quickly as possible. Large amounts of snow collected in small areas may lead to short-term undesirable asymmetric loads on the structure, and this may cause damage.

The snow loads on a glass roof are entirely different from loads on a well-insulated roof, where large amounts of snow can remain for long periods, and only an increase in air temperature will start the melting process. Recommendations are given later.



Overheating Due to Sun

Overheating during sunny days can be a problem for both the design and the people under the roof. Metal and glass designs are usually sufficiently elastic so that temperature fluctuations do not result in the destruction of seals and joints. Overheating for people usually means discomfort, which can be relieved by sun blinds under the glass roof and good ventilation systems.

Materials

Glass-covered areas exist in three types:

1. The area underneath is not heated (waiting room, etc.)
2. The room underneath is semi-air-conditioned, ie. the temperature inside is always well above freezing point, and some heat is transferred from buildings nearby and human activity (covered walkways, shopping centres, private winter gardens, etc.)
3. The temperature is always heated to the normal temperature for long-term human activity, ie. fully air-conditioned (hotels, office buildings, etc.)

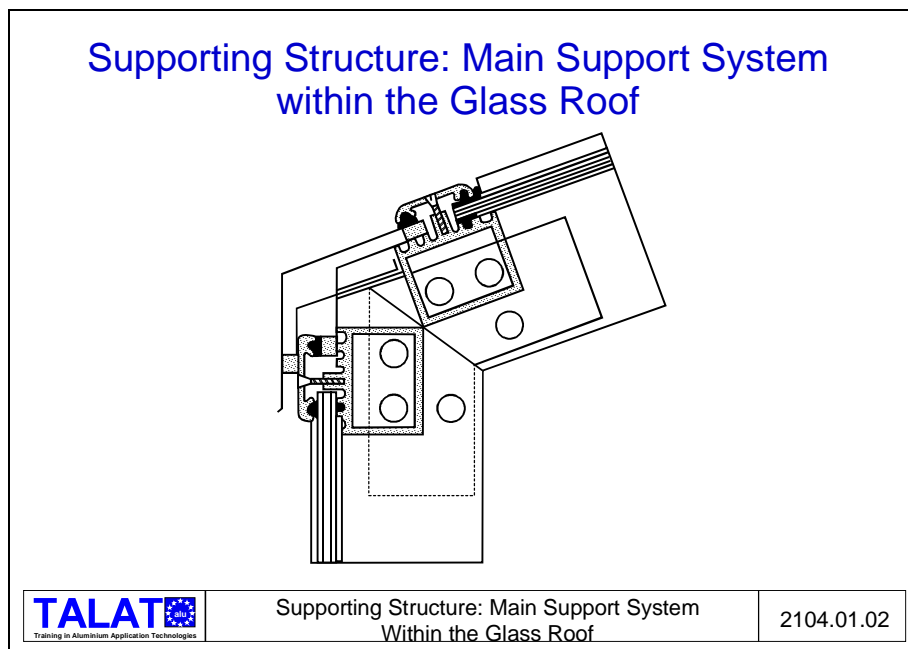
The choice of glass will vary according to the above mentioned types. In non-air-conditioned areas, only reinforced glass or polycarbonate sheets are used. Sealed double glazing units are most common for the other two types. For safety reasons, we recommend double panes, the outer pane in standard or tempered glass, and the inner pane in laminated glass. Should one of the panes break, the inner laminated glass is intended to prevent broken glass from falling into the covered area.

The glass manufacturers provide details of the maximum vertical deflection of the glass: max. 1/300, or max. 8 mm along the longest edge per glass unit.

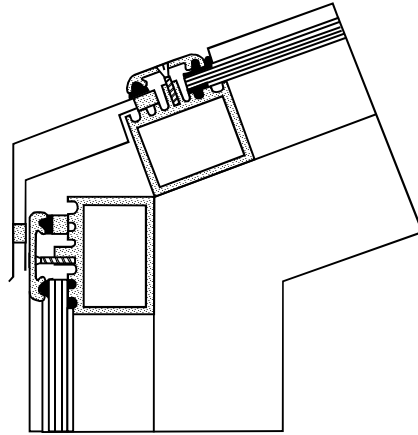
The supporting structure of the roof and the frames around the glass is either such that the main supporting system and the frames are in the same section, or else the support is made of another material and the frames make up a secondary system (**Figure 2104.01.02**).

The frames are normally made of extruded aluminium profiles, because channels and steps are easy to fashion during the extrusion process. A joint section for support and frames must therefore be made of a metal which lends itself to extrusion, ie. aluminium. If the support and frames are separate, the supporting section may, for example, consist of steel or a laminated wood structure, and the frames, the secondary system, of extruded aluminium (**Figure 2104.01.03**). Other materials in the frames have been tested, but without much success, and they have been removed from the market.

Many aluminium systems are designed as insulated systems, ie. the sections have a layer of insulation between the outer and inner parts of the section. The insulation normally consists of a plastics material with poor heat conducting properties, which is fixed between the inner and outer sub-sections by means of screws which are mechanically fixed between the sub-sections (**Figure 2104.01.04**).



Supporting Structure: Glass Roof as a Secondary Support System



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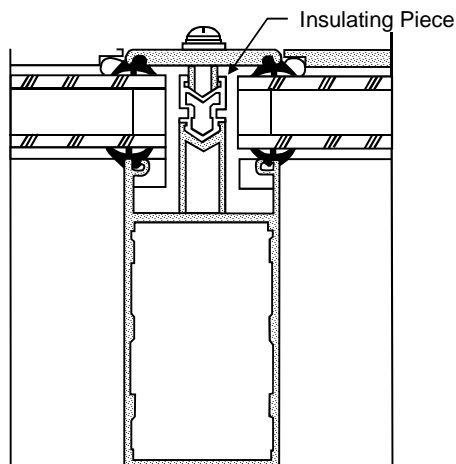
Supporting Structure: Glass Roof as a
Secondary Support System

2104.01.03

It is also acceptable to provide insulation by means of screws at a distance of >25 cm beyond the plastic section (**Figure 2104.01.05**).

Seals around the inside and outside of the glass are normally extruded sections in a rubber material. The seals in the cross-member intersection are of the same material. The screws through the outer roof section, which connect the two aluminium sub-sections, also serve to compress the packing around the glass.

Horizontal Section



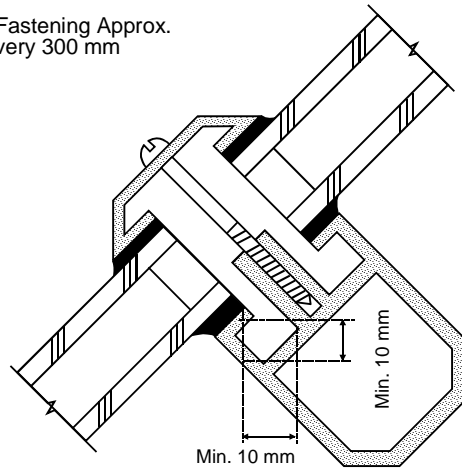
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Horizontal Section

2104.01.04

Insulation Through Distance and Screw Fastening

Screw Fastening Approx.
Every 300 mm



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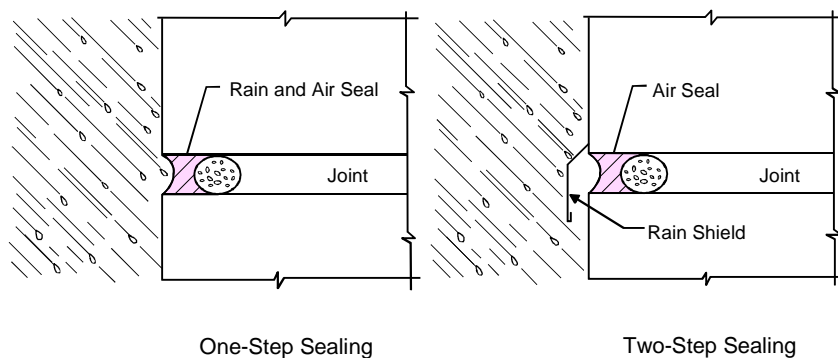
Insulation Through Distance and Screw Fastening

2104.01.05

Principles of Good Design

In order to allow the profile system in the roof to withstand climatic conditions consisting mainly of rain, the sections must be designed to provide absolute impermeability, even after wear and degeneration to certain materials used on the outside of the structure. It is, therefore, a requirement that the system is designed in accordance with the **two-step sealing** principle (Figure 2104.01.06)

Principle of Two-Step Sealing

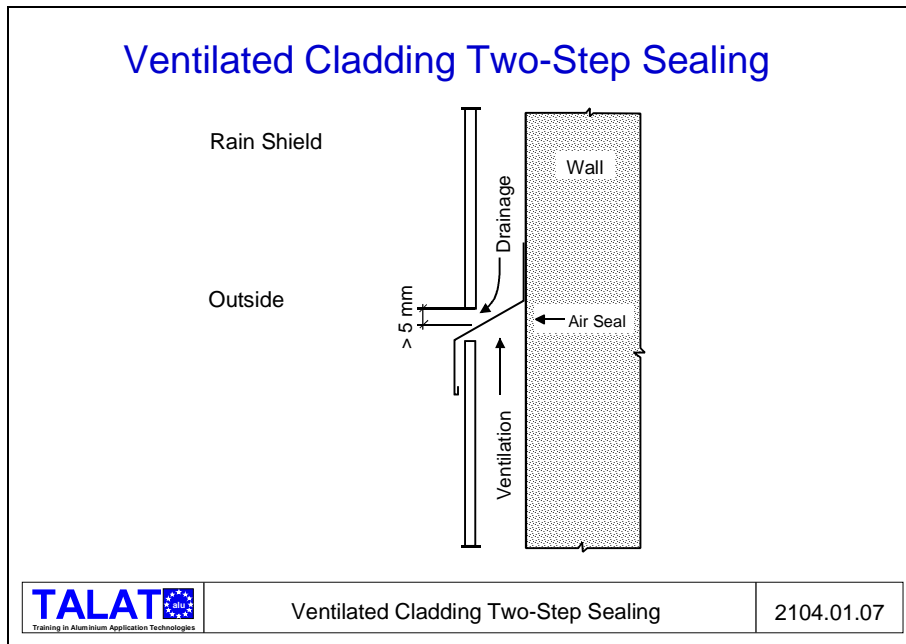


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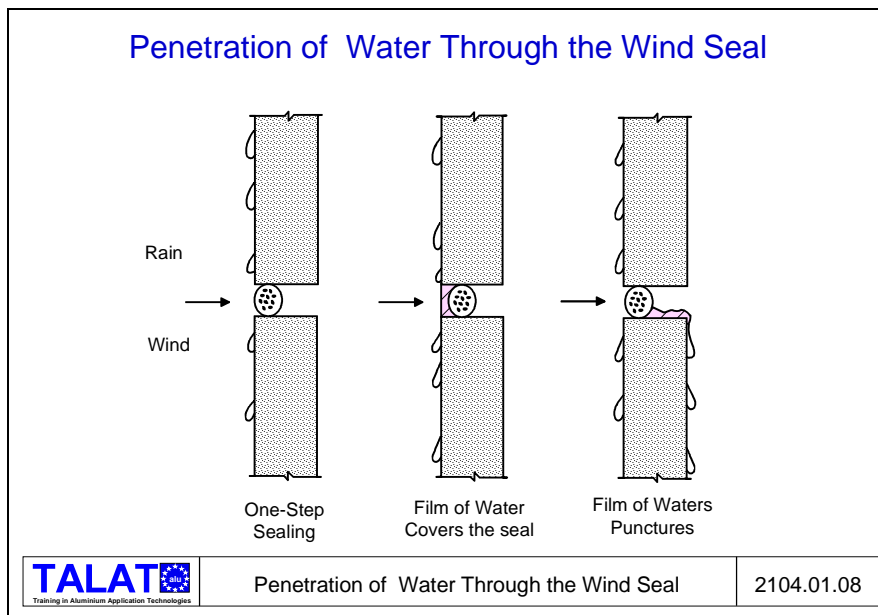
Principle of Two-Step Sealing

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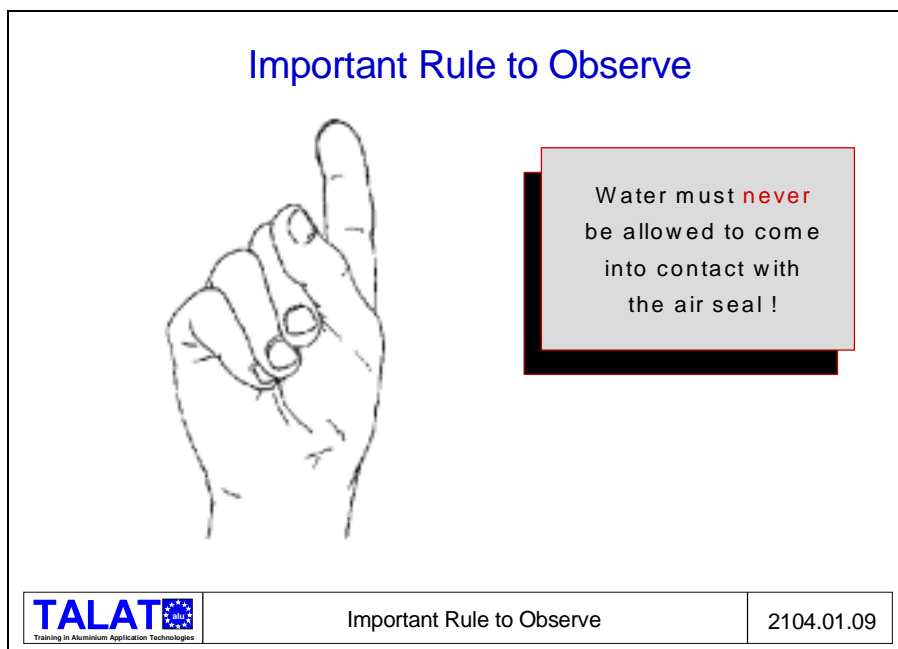
Two-step sealing means that the design includes an outer rain seal or rain shield (first step), and a separate internal wind seal (second step). The rain shield must as far as possible prevent rain from penetrating the structure and coming into contact with the wind seal. Between the two steps is a ventilated and drained area, which means that the total drop in pressure between the inside and outside of the roof, due to the effect of wind, occurs over the wind seal - characterised as the main seal (**Figure 2104.01.07**).



If the wind seal is moistened by the rain, the drop in pressure will occur over the film of water which has formed over the wind seal, and as it does not have the properties to withstand pressure, it will puncture at the weakest point of the wind seal, with guaranteed leaking to the inside (**Figure 2104.01.08**). If the rain is not allowed to come into contact with the wind seal, this kind of leakage never takes place.



Sections in glass roofs must, therefore, always be designed such that **penetrated water must never come into contact with the wind seal** (Figure 2104.01.09).

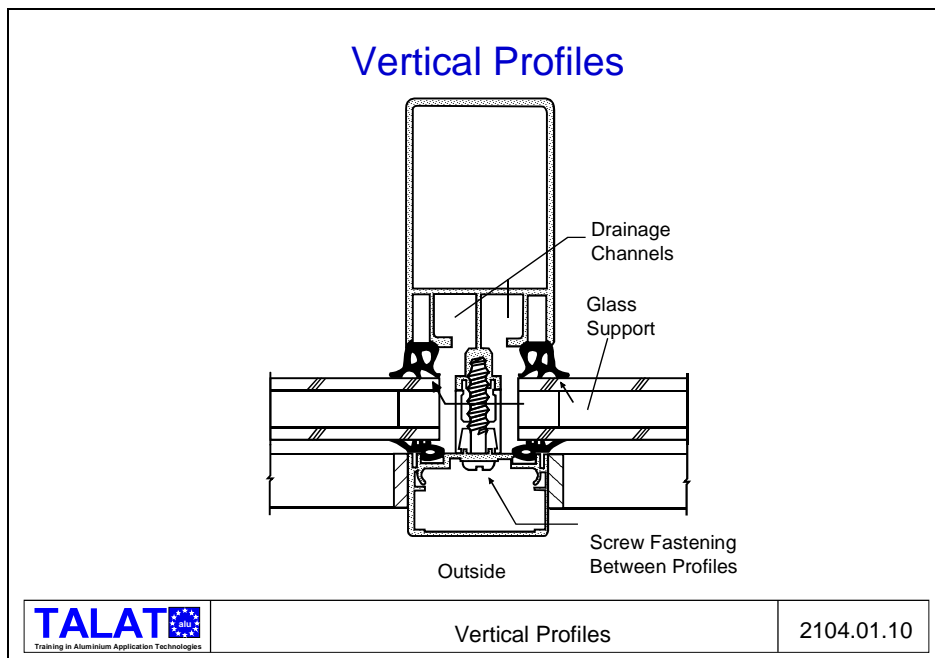


This principle is applied in vertical facades and most types of windows with good results. Glass roofs should not be an exception. We know from experience and tests that seals exposed to the outside never remain absolutely watertight for a long period, and so

we must develop our designs on the basis of these conditions, including a drainage channel behind the rain shield.

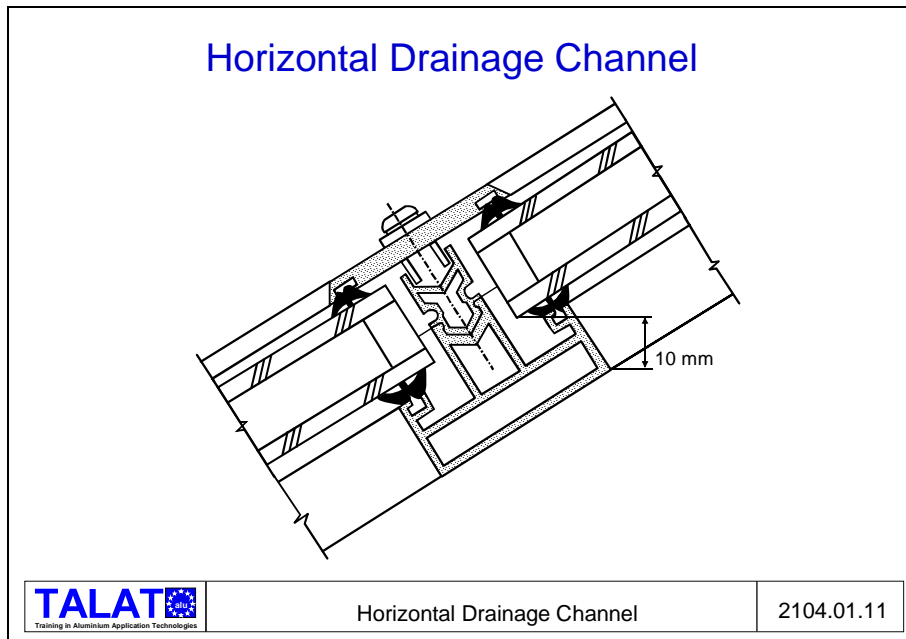
Drainage

A number of requirements need to be met for the proper operation of the drainage system. The most important of these is that the system should be positioned so that any penetrated water is collected by the drainage channel, which is kept away from the air seal. Next, the channels must have certain minimum dimensions allowing the water to flow freely without becoming attached to more than one side of the channel simultaneously. The dimensions are calculated on the basis of the size of a water droplet, which is around 4.5 mm in the horizontal or vertical plane. A vertical drainage channel therefore needs to be wider than 5 mm to prevent the droplet's water tension from fixing the droplet to the sides of the channel, thus hindering good drainage. The channels are recommended to be no less than 8 mm wide. A wider channel would be even safer, but we must bear in mind that from an architectural point of view, an aluminium section of a glass roof should not have a total breadth of more than 50-60 mm, and that this size needs to provide room for two glass supports, two drainage channels and sufficient means of fastening the outer roof section (**Figure 2104.01.10**). The depth of the section also varies according to the span.



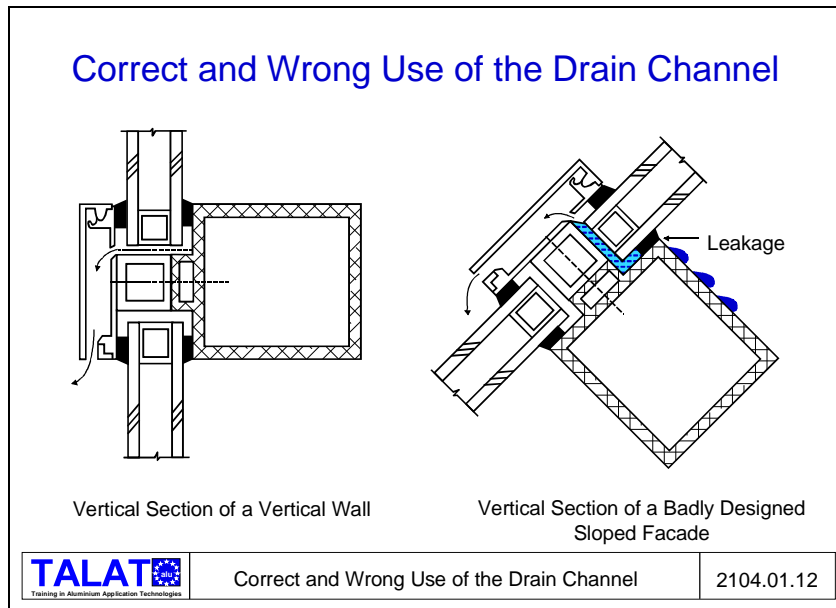
A horizontal drainage channel should also be deeper than 5 mm to prevent water coming into contact with the inner glass packing. A certain amount of flexing of the horizontal

cross member must be assumed, and for this reason a depth of at least 10 mm is recommended (**Figure 2104.01.11**).



In the case of facades, the aim is to drain out any penetrated water through holes in the horizontal cross member of each piece of glass. With a roof, however, the water will try to penetrate into the sections.

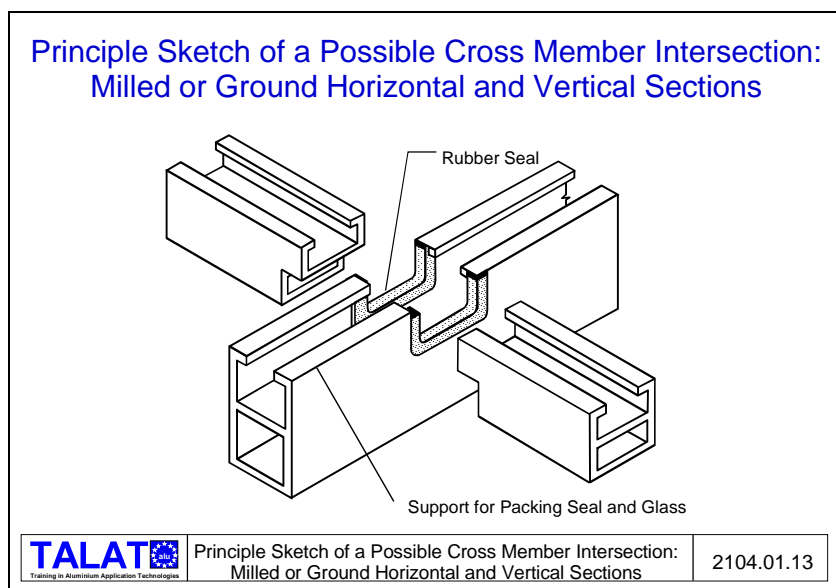
Water in the horizontal cross members of a roof should, therefore, be conducted sideways to the nearest vertical section, which then acts as an outlet pipe to the outside at the bottom of the roof. In large glass roofs, a relatively large amount of water may need to be conducted through the sections, and it is vital to get the position and dimensions of the drainage channels right. The considerable damage caused by leaking in glass-covered areas built in the early '80s can usually be traced back to the drainage channels being of an insufficient number or size. The experience with vertical facades was good with regard to impermeability and durability, and the same principles were applied to roofs. Of course, this proved to be impossible and consequently, damage occurred (**Figure 2104.01.12**). Combining the wall and roof systems is difficult, and the starting point must always be the roof system, with a subsequent adaptation to the wall system. A wall system used as a roof seldom, if ever, works. A roof system used as a wall may be possible.



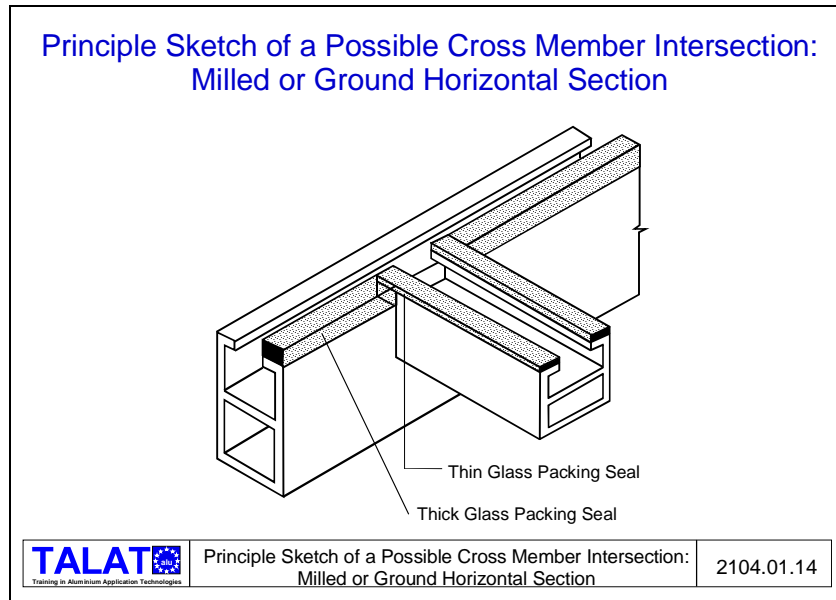
Joins, Cross Member Intersection

As the drainage water flows from the horizontal glass flanges towards the vertical sections on both sides, it needs to pass over a connection between the sections in the cross member intersections. This connection needs to be absolutely watertight, and no water must be allowed to come into contact with the inner air seal around the glass, the main seal. Such connections are currently executed in one of two ways.

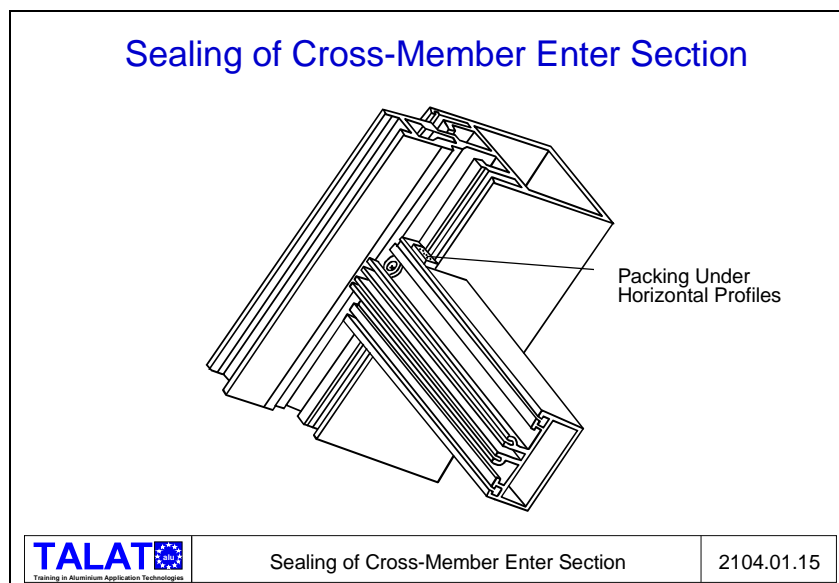
One method is to mill or grind out sections of the horizontal and vertical sections, and to seat the horizontal section within the vertical section such that the glass supports are at the same level in both sections (**Figure 2104.01.13**).



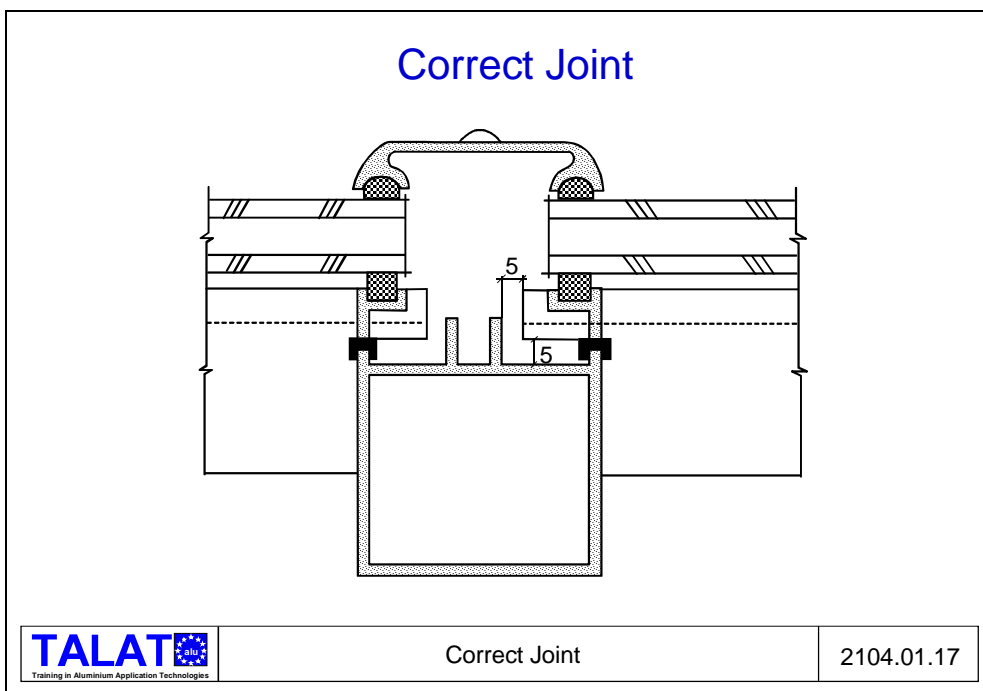
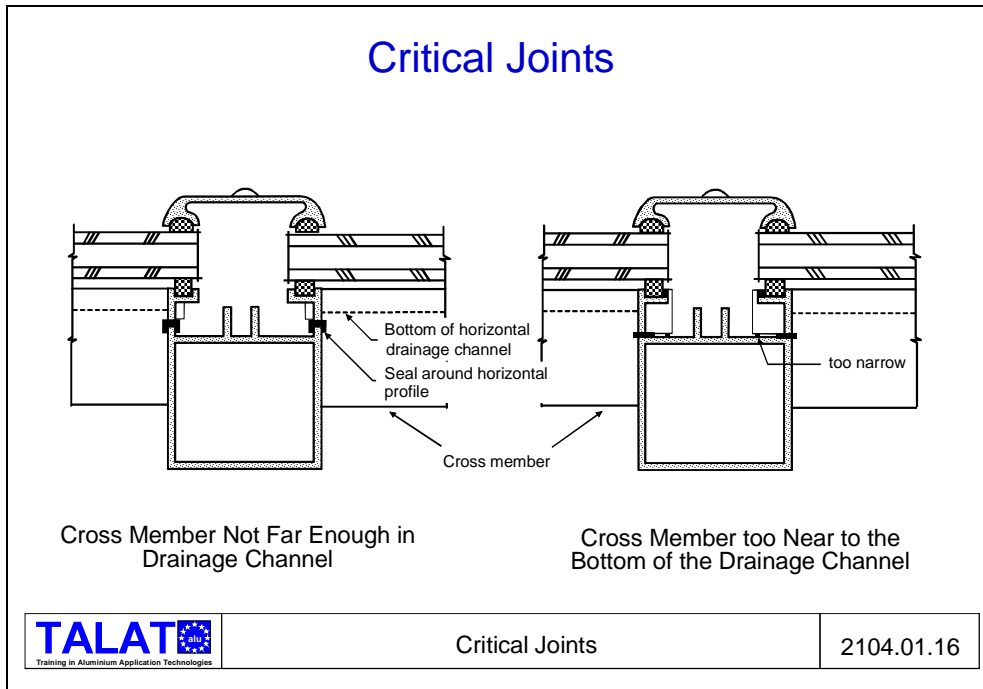
Another method is to mill or grind only the horizontal section and lay it into the vertical section with a considerable overlap. The difference in level of the glass supports is evened out using a higher inner packing seal for the glass in the vertical sides (**Figure 2104.01.14**).



A requirement of both solutions is that the connection between the aluminium sections must be watertight. This is achieved using a ready-shaped rubber sealant covering the sides and the base of the horizontal section, and which is compressed as the horizontal section is fastened to the vertical section at the intersection. Grouting used as a sealant in these areas usually has a short service life, and will require frequent maintenance (**Figure 2104.01.15**).



The distance to which the horizontal sections are seated in the vertical sections is also critical. Water in the horizontal sections must be conducted far enough into the vertical sections so that it cannot come into contact with the seal. On the other hand, the distance from the horizontal drainage channel to the base of the vertical section must not be so small that the capillary effect draws water towards the air seal around the glass (Figure 2104.01.16). In both cases, a minimum distance of 5 mm is a good rule of thumb (Figure 2104.01.17).



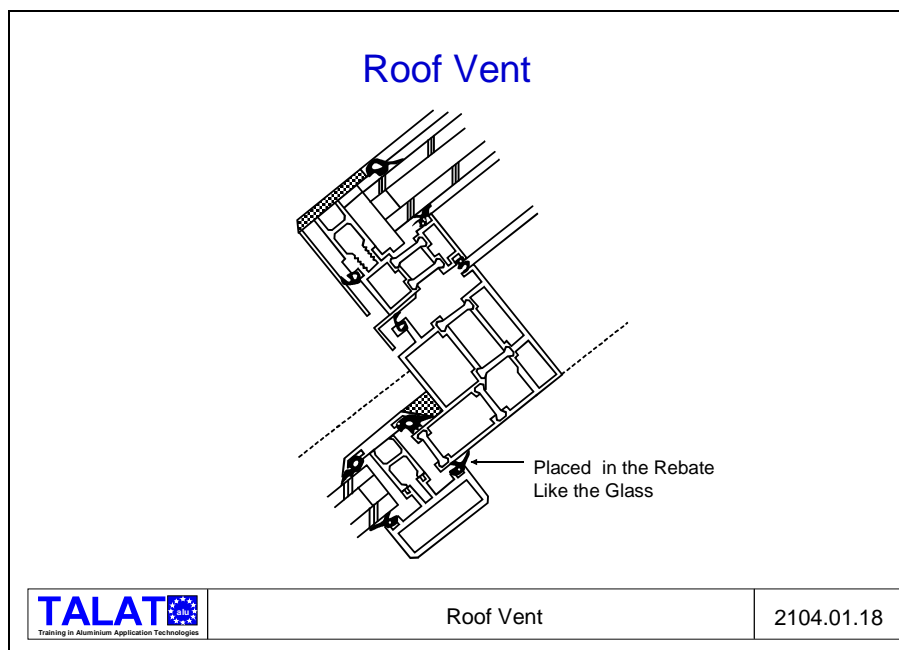
Transitional details

The designer of a glass roof system is not only charged with ensuring the good operation of the glass roof, but also that the details of the transition between the roof and the adjacent buildings are suitable, efficient and impermeable.

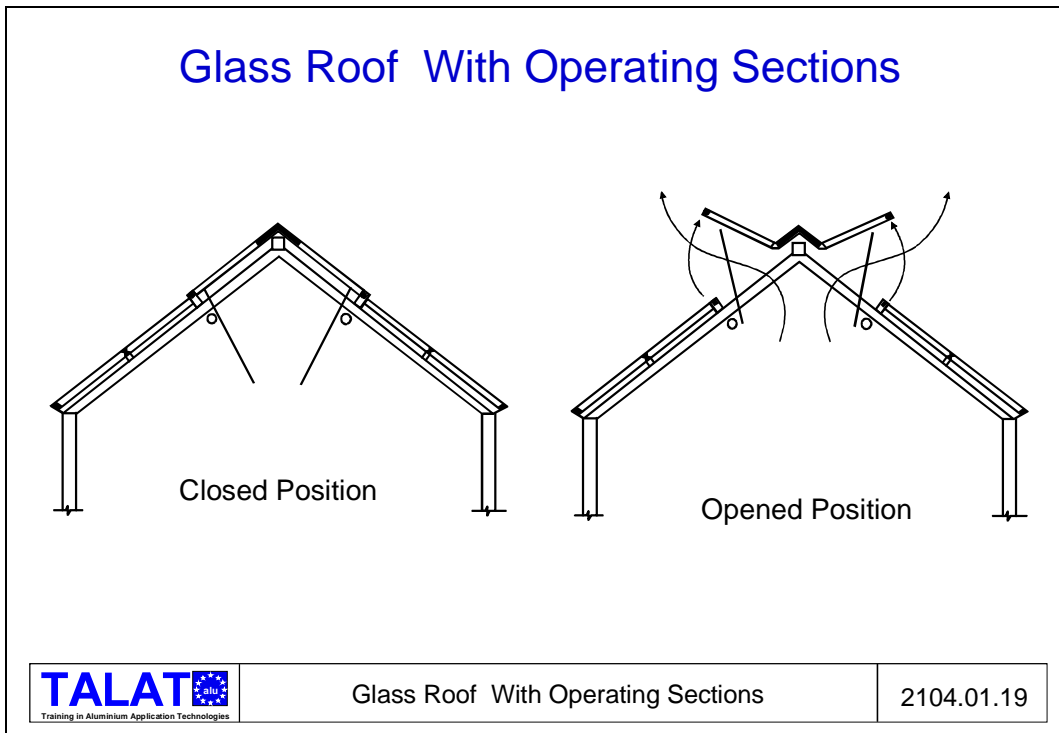
Where the buildings are new, these details can be dealt with in collaboration with the facade builder if the contract is split. The situation is worse in the case of attaching glass roofs to existing buildings. Such details may be left to the craftsman carrying out the work, and the results can vary considerably. In principle, these details should be dealt with beforehand by the roof manufacturer, in order to ensure the proper functioning of the roof with all its junctions and connections with the surrounding buildings. Leaks from the transitional sections let down an otherwise good roof system.

Roof vents, ventilation

The effect of the sun may produce uncomfortably high temperatures in the area beneath the glass roof, and ways must be found to solve this problem. Sun blinds under the glass can be used to prevent the effects of direct radiation, and vents in the roof allow some of the heated air to escape. The dimensions of the vent in relation to the surface area of the roof are based in principle on the fire ventilation requirements of the different types of covered area. The requirements are laid down in national building regulations and they may be different from country to country. The vent must open automatically in the event of fire, using a smoke detector, but it should also be possible to open it manually for other kinds of ventilation (**Figure 2104.01.18**).



The vents form an integral part of the glass roof, and must naturally be impermeable, both with regard to the vent structure itself, as well as the joint between the opening parts of the vent and the frame. In glass roof systems, ready-produced vents are fitted into the system in the same way as the panes of glass. The action of opening and closing may be carried out manually in smaller glass roofs, but in larger structures, a motorised rack and pinion assembly is the most generally used (**Figure 2104.01.19**).



Cleaning

Soiling of the external surface of the roof is highly dependent upon the level of air pollution in the surrounding area. Experience has shown that the need for external cleaning is much less than might be expected. Rain and, where applicable, snow, have been found to be sufficient to keep the roof relatively clean, even in areas of high atmospheric pollution.

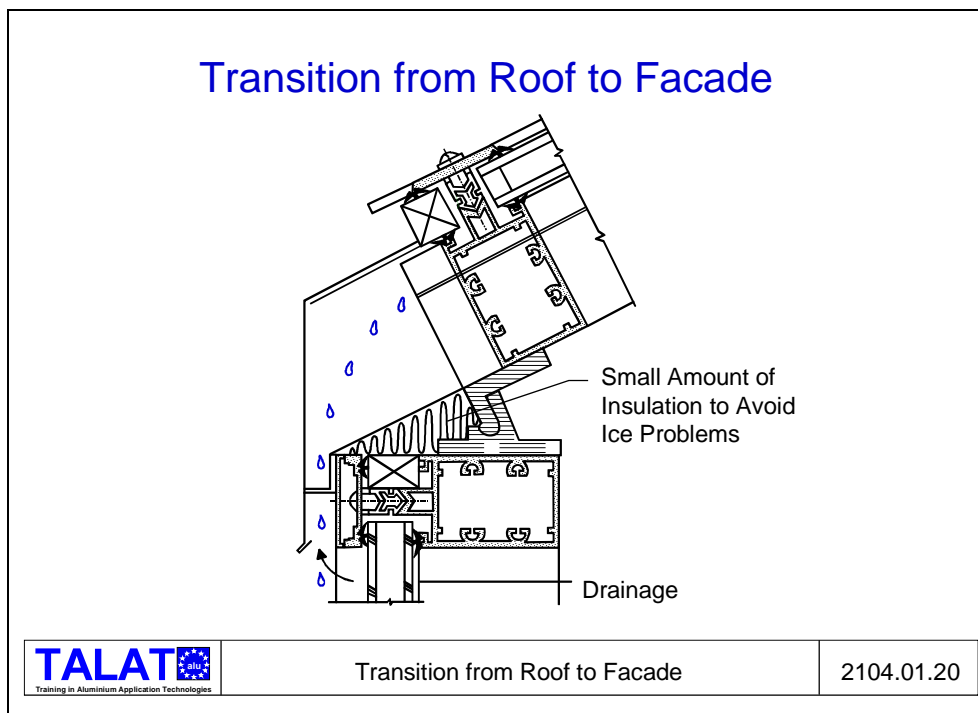
Internal soiling may be a more significant problem because of dust and other contamination in the air inside. Permanent equipment should therefore be provided to allow the safe cleaning of the internal glass surfaces of larger structures. There are many types of cross-arms and hoists for this purpose, and these must be included as an integral part of the design of the glass roof.

Behaviour in winter

In countries with cold winters, glass roof design runs up against a number of special problems. Snow loads are dealt with under "Effects of climate".

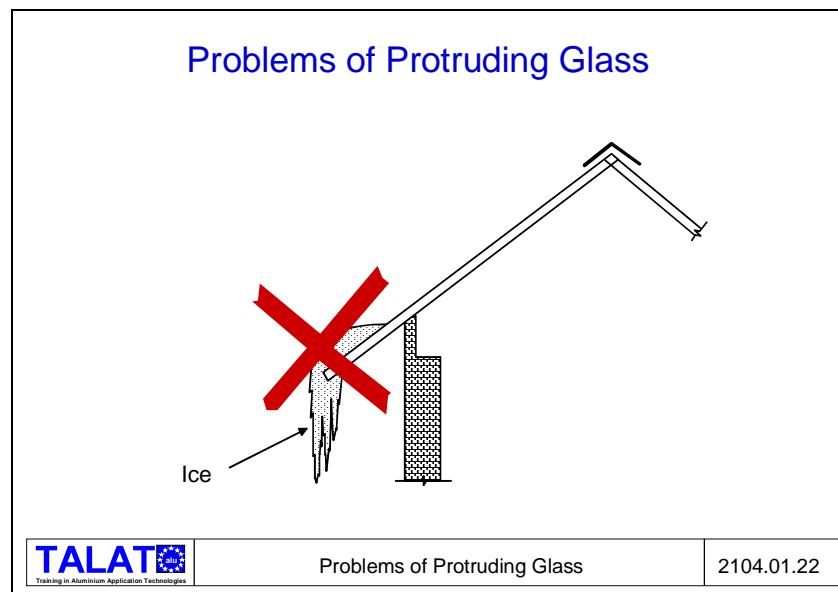
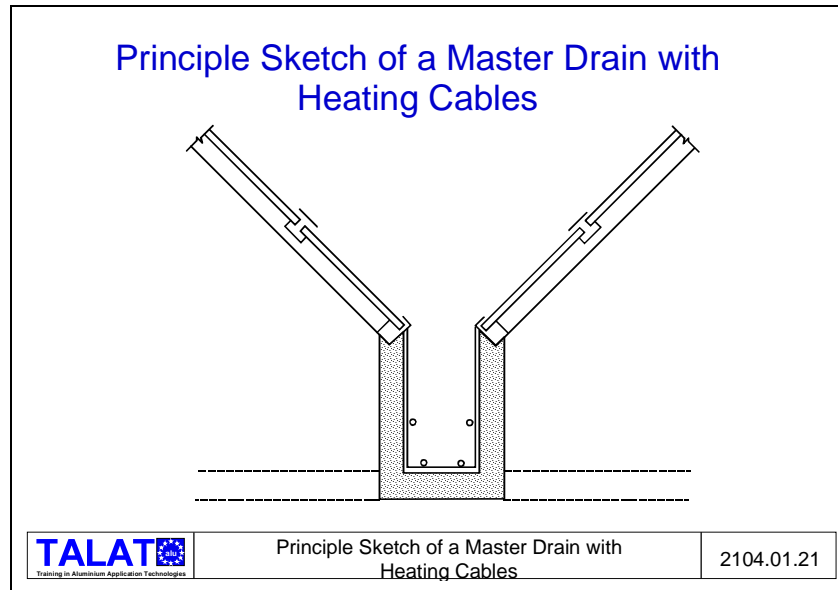
In order to allow snow to melt quickly, the glass, which makes up 80-90% of the roof, must not be too well insulated. Snow sitting on the glass takes away half the point of having a glass roof. Experience shows that a U-value of 2.0-3.0 W/m²K gives adequate melting properties, even at low outside temperatures, and in fully or semi-air-conditioned areas.

All transitions between the roof and other building parts, which are normally covered with metal fittings, must not be insulated too well either, because melted snow will immediately freeze to ice on well-insulated fittings (**Figure 2104.01.20**). On a change of weather, the lumps of ice come loose and represent a considerable risk to people and objects outside the building.



The U-value in transitional sections must therefore be the same as for the glass in order to keep the water unfrozen until it has escaped through a drain. The drains should also be of a size capable of dealing with considerable quantities of melted snow, as well as being equipped with heating cables to continue the melting process, even after the effect of the loss of heat through the roof has ended (**Figure 2104.01.21**). The size of the heating cables depends on the melting requirements and the general climatic conditions in the area. Protrusions from the purlins, where the temperature may be the same above and below the glass, must be avoided, because the formation of ice there will be a

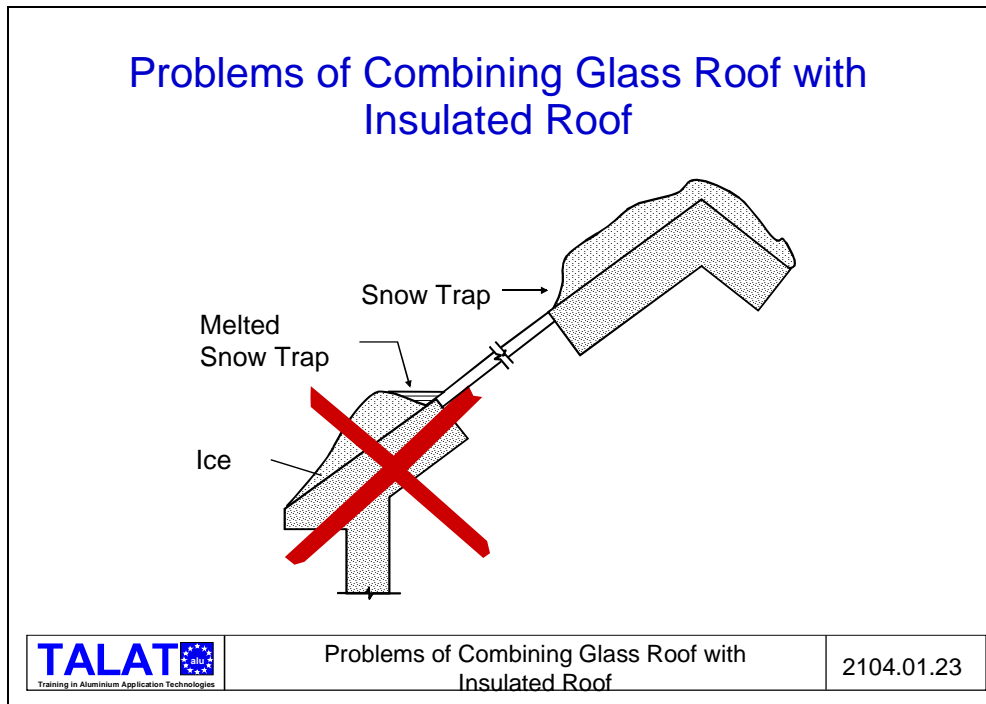
problem, possibly leading to the glass breaking or lumps of ice falling (**Figure 2104.01 22**).



The combination of glass roofs and different, well-insulated roof surfaces may cause the formation of ice. If the insulated roof is above the glass roof, and the glass is directed downwards towards a final outlet drain, then the roof will work well. Snow will remain of the insulated part and melt on the glass roof.

If the glass roof is above the insulated roof, however, the melted snow from the glass freezes immediately on contact with the insulated areas, and during winters with a high snow-fall, a large amount of ice may be collected. Large quantities of ice may result in

damage to the roofing material and unwanted asymmetrical loads on the roof structure. (Figure 2104.01.23).



Condensation

Condensation on the glass and the sections in colder regions has been a much less serious problem than first expected. The relatively high temperatures immediately below the roof allow high levels of moisture absorption in the air without increasing the relative air humidity. Even in covered areas containing high quantities of water, the surface temperature of the internal surface of the glass is sufficiently high to prevent condensation forming at low outside temperatures.

If the vapour barrier between the glass roof and the other parts of the building is not effective enough, humid inside air may be allowed to penetrate the structure and condense on contact with a colder outer surface. The result of this may be unwanted damage from corrosion and perhaps frost.

Condensation sinks along the inside of the aluminium sections have been found to be unnecessary under normal circumstances. Where condensation sinks are required by specific internal conditions, one must provide the sinks with a separate, closed outlet system, as any connection with the drainage system of the structure would perforate the overall roof system and would result in an unacceptable through-flow of air. The drainage system has an outlet for water, which means that it also has an inlet for air to circulate within the sections.

General advice on the design of the glass roof

- The design must be based on the principle of the two-step seal.
- Make sure that all transitions between sections are absolutely impermeable, and that any screw fastenings to a main support system do not block the path of drainage water.
- Investigate the climatic conditions of the intended destination of the glass roof in order to select the right section system and type of glass.
- Investigate local regulations with regard to fire ventilation and, where applicable, snow loads, in order to choose the right dimensions of the vents and, perhaps, the sections themselves.
- For sloping facades - think in terms of roof design.
- After erecting the aluminium supports or framework, all the channels in the sections must be cleaned before fitting the glass.

Literature

Byggforsk, Håndbok 36, 2. edition. "Glasstak Konstruksjoner. Klimapåvirkninger og løsninger for nordiske forhold" (Glass Roof Design. Effects of climate and solutions for Scandinavian conditions)

Byggforsk, Håndbok 41. "Fassader og glass av metall" (Metal and glass facades)

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