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Rain Penetration in Joints

Influence of Dimensions and Shape of Joints on Rain Penetration

By TRYGVE ISAKSEN

Norwegian Building Research Institute

NORWEGIAN BUILDING RESEARCH INSTITUTE

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RAIN PENETRATION IN JOINTS. INFLUENCE OF DIMENSIONS AND SHAPE OF JOINTS ON RAIN PENETRATION

TRYGVE ISAKSEN

Norwegian Building Research Institute, Trondheim
Norway

1. GENERAL REMARKS ABOUT WIND AND RAIN

The joint is a part of the wall and should protect us against the outside climate as well as the wall itself. It must keep out driving rain, running water, hail, sleet and snow without regard to windforce, duration of the gale or position and exposure of the building. Even if driving rain onslaughts have been measured during 10 years on free stations, we cannot predict exactly how much rain that will hit the exterior walls of a neighbouring building, and we have no clear picture of the distribution of rain over the windward wall of the building. Some observations from practice tell us that the amounts of water running down a high wall can be great.

During a rain storm in Aalesund, (a Norwegian town facing the Atlantic), the water was seen running down like a film on the inner side of an unrendered brick leaf. The wind gusts made waves in the film as they pressed water through the joints.

A similar rain penetration was observed last autumn in the outer leaf of a cavity brick wall in Trondheim, see Fig. 1. The building is severely exposed to rain and wind, and during the erection the open drainage joints at the bottom of the cavity had to be sealed and were replaced by a few bent tubes opening downwards. In the brick itself, the holes were filled with water.

On a leaky curtain walled high house in the Oslo-area, the 5 ··· 6 hour old rain (salt) marks were just covered by us when we sprayed 60 ··· 70 l water (per meter horizontal) on the wall, see Fig. 2. The building rises 12 storeys above our spraying place, and could not be hit by more than 1.5 l/m^2h during the preceding night if the traces on the windbarrier were correct. There was no wind when we sprayed on the water, but the penetration occurred 1 ··· 2 storeys farther down.

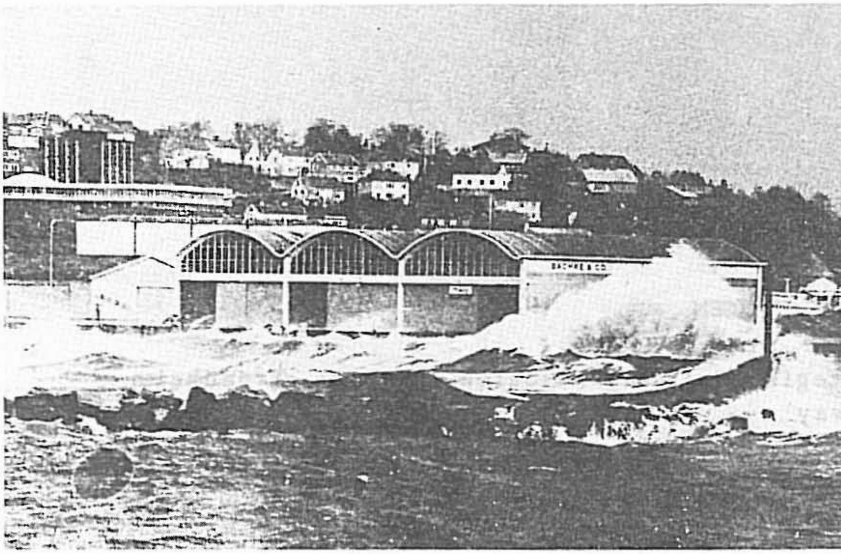

Figure 1. Gale in Trondheim October 1964. Heavy onslaughts of driving rain on high house to the left.

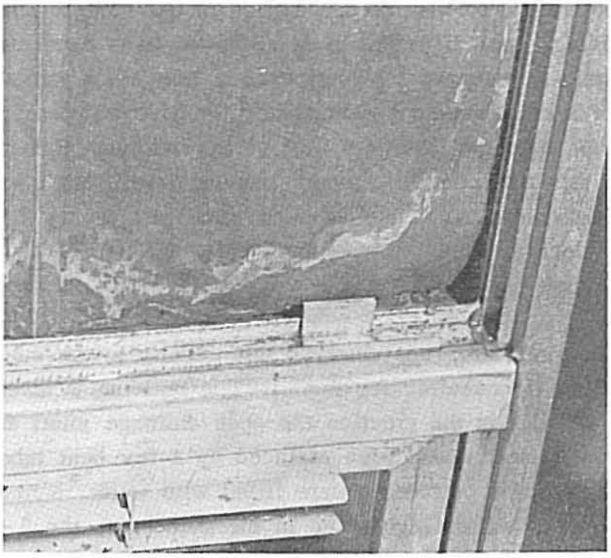

Figure 2. Water penetration in joints around spandrel glass edges. Water marks on the wind barrier.

The examples from brick walls are by no means new, water usually penetrates the joints even when the workmanship is rather good. The joints in the curtain wall were not constructed to withstand neither driving rain nor running water.

Exact data of driving rain require simultaneous recording of wind-speed and -direction. In Norway the amount of driving rain is measured only once a day at the 4 main weather stations (Oslo, Bergen, Trondheim and Tromsø), not recorded. The driving rain gauges are freely exposed, wall-cups have not been used.

On a small test house (3 ··· 4 m high) at The Norwegian Technical University in Trondheim, driving rain was measured once a day both in a free-standing gauge and in a wall-gauge facing the west. The wind was recorded 15 m above the test house.

Fig. 3 shows the measured amounts of driving rain in the period 1954 ··· 1962. In 1955 the total amount of driving rain (from the 4 main directions) exceeded the vertical precipitation. This year more rain than 240 l/m^2 hit the west wall, the average being ab. 150 l/m^2 per year. November 1955 was especially wet and windy, and 94.1 l/m^2 fell on the west wall i.e. more than 3 l/m^2 per 24 hours. Fig. 4 shows that total amount of driving rain (from 4 directions) in Nov. 1955 was more than 1.6 times greater than the vertical precipitation, and that driving rain amounts from west alone (in the freestanding gauge) equalled the vertical precipitation.

The heaviest onslaughts came during the week from the 21. to the 28th November, when the total amount of driving rain was more than the double of the precipitation. Average wind speed was 7.3 m/sec. direction varying from S to N over W (see Fig. 5). The west wall was hit by 0.5 l driving rain per m^2 and hour the whole week.

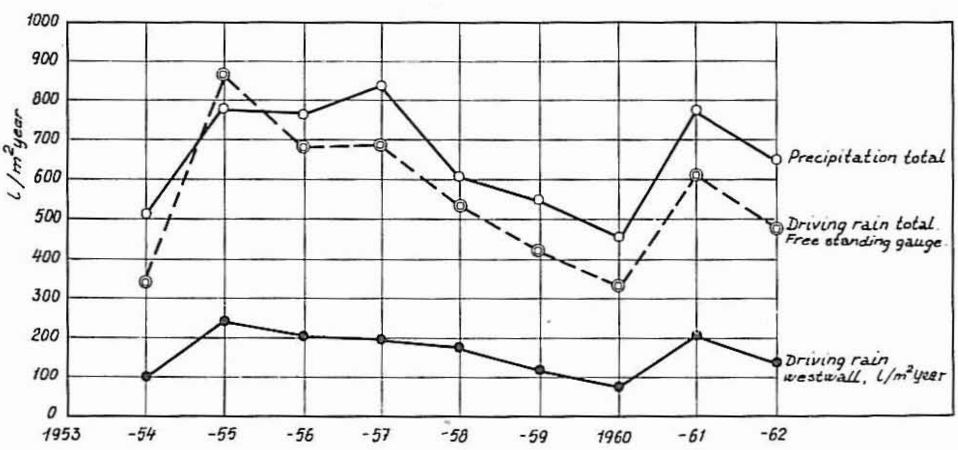

Figure 3. Driving rain and vertical precipitation measured on test house N.T.U. 1954 ··· 1962.

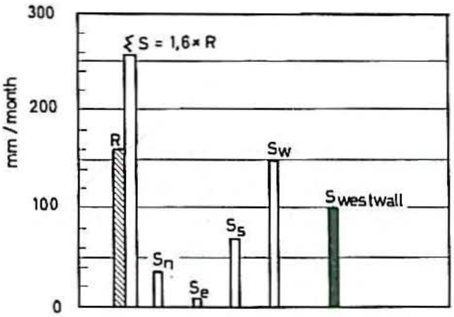

Figure 4. Precipitation and driving rain in November 1955 at N.T.U. Trondheim.

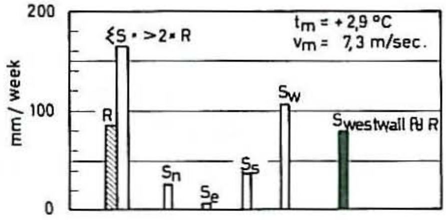

Figure 5. Precipitation and driving rain during the week 21 ··· 28 Nov. 1955 at N.T.U. South-West wall = 0.5 $1/m^2h$.

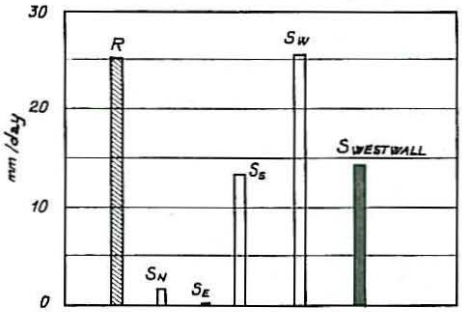

Figure 6. Precipitation and driving rain on the 26th Nov. 1955. South-West wall = 14.15 mm. South-West wall = 0.6 $1/m^2h$.

On the 26th November the west wall got 14.2 $1/m^2$, or 0.6 $1/m^2h$, see Fig. 6. Unfortunately the measurements were only done once a day, in 1949, however, amounts corresponding to 6.6 $1/m^2h$ were measured during a 10 min. period. The test house was rather low, and the wind speed around the rain gauges was probably not as high as the 7.3 m/sec average measured 15 m higher up.

On the Norwegian west coast both precipitation, driving rain and wind are stronger than in Trondheim. In Bergen a precipitation of 50 ··· 60 mm per day can be measured in F7, and Bergen is far from being the worst place, sheltered as it is by 7 mountains. Table 1 gives the amounts of driving rain measured in Bergen (Met. st.) and Trondheim (Met. st.) and N.T.U. in 1962. The precipitation in Bergen is 4 times that of Trondheim, and if the wind speed is the same on both places, the difference in amount of driving rain ought to be proportional. In the example quoted above, (see Fig. 5) the Bergen wall should be hit by max 2.4 $1/m^2h$ at a wind speed = 7.3 m/sec. over a day.

Table 2 presents a climatic survey for Gothenburg, Bergen and Trondheim for 1962. The precipitation was about the same in Gothenburg and Trondheim, while

Table 1. Precipitation, driving rain and wind in Bergen, Trondheim (Voll met. st.) and N.T.U. Trondheim 1962.

	Precipitation mm	Driving rain mm N E S W	Driv. rain West wall $1/m^2$ year	Remarks
Bergen	2044	$\underbrace{83.6 \quad 464.8 \quad 912.6 \quad 55.4}$ ≅ 1520 $1/m^2$ year (March lacking)	Not measured	Driving rain total ≅ 76 % of vertical precipitation (11 months driv. rain)
Trondheim (Voll)	979	$\underbrace{54.6 \quad 33.6 \quad 226.0 \quad 247.3}$ ≅ 562 $1/m^2$ year (April lacking)	Not measured	Driving rain total ≅ 60 % of precipitation (11 months driv. rain)
Norw. Tech. University Trondheim	641	$\underbrace{44.2 \quad 41.4 \quad 175.6 \quad 257.8}$ ≅ 475 $1/m^2$ year	135.6	Driving rain total = 74 % of precipitation. Driving rain on west wall in % of driv. rain in free standing gauge: Max. 90 % (Nov.), Min. 4,2 % (May), Average = 53 %.

Bergen has got more than the double. Gale was measured on the coast outside Gothenburg, data from Torslanda airfield (Gothenburg met. station) are lacking.

It is interesting to notice that gale on the Swedish west coast sometimes coincides with heavy rain, sometimes not. The walls in Gothenburg could be wetted in a short time and dry out as quickly if the water does not penetrate far into the wall.

The number of sun visible hours per year was 30 % higher in Gothenburg than in Bergen and Trondheim. All three towns get most of the driving rain from the sector S to W, and since Trondheim has twice as many frost days as Bergen and 1.5 times Gothenburg's, walls in Trondheim facing west or northwest will have the worst drying conditions during the winter. In Bergen the air temperature is not frequently below zero, and the wind will here have greater opportunies to dry out wet walls than in Trondheim.

How the amounts of driving rain hitting the windward wall depend on the height of the house, we do not know. British measurements, quoted by Mr. R.E. Lacy,

Table 2. Meteorological data for Gothenburg, Bergen and Trondheim 1962.

Month	Mean temp.	Frost days	Number wind days			Sun h	Precipitation mm	Precip. max. per day	Remarks
			$F \geq 6$	$F \geq 8$	$F \geq 9$				
January									11. and 31. Vinga and Varberg: Gale SSE and S. Simultaneous precip. Gothenburg 9.0 mm and 5.1 mm.
Gothenburg	1.4	11			2	52	90	14.9	
Bergen	3.3	6	19	1	1	10	332	34.4	
Trondheim	-1.5	23	9	1	1	7	62	10.2	
February									1, 11, 12, 15, 16, 17th: Vinga and Varberg: Gale SW, WNW, S, W, N. Precipitation Gothenburg: 10.9 ··· 7.8 ··· 2.1 ··· 17.0 ··· 0 ··· 0 mm.
Gothenburg	1.2	20			6	126	80	17.0	
Bergen	2.3	13	15	4	1	83	264	45.2	
Trondheim	-1.4	25	4	1	-	50	117	17.9	
March									
Gothenburg	-1.1	27			-	157	32	7.0	
Bergen	0.4	22	5	-	-	101	49	9.9	
Trondheim	-4.1	31	2	-	-	126	56	8.4	
April									
Gothenburg	6.5	3				199	52	16.4	
Bergen	5.7	5	7	-	-	209	84	24.9	
Trondheim	2.7	15	1	-	-	148	37	6.5	
May									
Gothenburg	9.1	1			-	173	71	11.8	
Bergen	8.9	-	4	-	-	190	76	22.5	
Trondheim	6.9	4	2	-	-	182	30	7.0	
June									
Gothenburg	13.8	-			-	289	35	9.5	
Bergen	11.0	-	2	-	-	172	116	24.7	
Trondheim	9.0	-	-	-	-	135	126	16.0	
July									
Gothenburg	15.1	-	-	-	-	263	87	21.7	
Bergen	13.8	-	1	-	-	200	31	7.4	
Trondheim	11.7	-	1	-	-	184	55	21.6	

Month	Mean temp.	Frost days	Number wind days			Sun h	Precipitation mm	Precip. max. per day	Remarks
			F ≥ 6	F ≥ 8	F ≥ 9				
August									27. Varberg. Gale
Gothenburg	14.1	-	-	-	1	214	217	33.8	SSW. Precip.
Bergen	12.7	-	4	-	-	136	314	36.6	Gothenburg = 8.8
Trondheim	11.7	-	2	-	-	164	113	19.2	mm.
September									
Gothenburg	11.9	-	-	-	-	167	100	31.1	
Bergen	10.9	-	5	-	-	77	191	26.6	
Trondheim	8.9	-	5	-	-	112	126	26.9	
October									28. and 30. Vinga:
Gothenburg	10.3	-			2	91	76	28.0	Gale S and SSW.
Bergen	9.1	-	13	-	-	53	298	49.0	Precip. Goth. =
Trondheim	6.1	5	10	-	-	52	113	19.3	11.2 and 28.0 mm.
November									14. and 15. Vinga:
Gothenburg	3.6	9			2	63	63	26.8	Gale SW. Precip.
Bergen	4.1	9	6	-	-	34	157	30.4	Goth. = 13.9 and
Trondheim	-0.4	17	6	-	-	33	63	22.8	1.3 mm.
December									14. and 15. Vinga:
Gothenburg	-0.9	22			2	36	64	15.2	Gale SE and S.
Bergen	1.5	18	9	1	-	16	132	28.2	Precip. Goth. =
Trondheim	-2.4	26	10	1	-	9	83	20.2	15.2 and 0.0 mm.
Total									
Gothenburg		93			15	1830	967	33.8 →	19.8. 1962
Bergen	7.2	73	90	6	2	1282	2044	49.9 →	16.10.1962
Trondheim	4.7	146	51	3	1	1200	979	26.9 →	7.9. 1962

BRS, show that maximum rates on the top of a 30 m high building in Glasgow can be more than 100 l/m^2h over a minute, while the total amount of driving rain was 6 l/m^2h because the storm lasted for only a few minutes.

The distribution of driving rain on the windward wall is not measured. Experience shows that parts near corners and eaves are severely exposed. We know that water running down a wall will be led against vertical protrudings or joints by the wind, and British measurements show that 3 ··· 4 m high joints get in 20 times as much water from the sides as from direct hits if they are not sheltered by flanges or protrudings along the outer opening.

We know too little about driving rain, we should record hits and running water amounts on existing buildings and on free weather stations simultaneously. The aim should be to find connections between normal meteorological data of wind

Table 3. Artificial wind in NBRI's driving rain app. - measured windforces in Gothenburg, Bergen and Trondheim.

	F = 0	F = 6 and 7 v = 10.8 ··· 17.1 m/sec.	F = 8 v = 17.2 ··· 20.7 m/sec.	F = 9 v = 20.8 ··· 24.4 m/sec.	F = 10 v = 24.5 ··· 28.4 m/sec.	F = 11 v = 28.5 ··· 32.6 m/sec.	F = 12 v = 32.7 m/sec.
NBRI Lab. Trondheim	Sometimes used		Usually steady wind = 20 m/sec.		Usually 14 ··· 42 m/sec. gust speed 6 t. per min.		Usually 33.5 m/sec. steady
Gothenb. Torslanda		Measured 79 times per year (10 year average, 10 min. periods)	8 times per year, 10 min. periods	0.5 ··· 1.5 times per year 10 min. periods	–	–	–
Bergen		23 times per year (10 year average). In 1962: 82 times	2 times in 10 years. 1962: 4 times	1 time in 10 years. 1962: 2 times	–	–	–
Trondheim		46 times per year. (1962: 47 times)	2 ··· 3 times per year. (1962: 2 times)	1 time per year. (1962: 1 time)	–	–	–
Kinn		190 times per year	51 times per year	23 times per year	3 times per year	1 ··· 2 times per year	–

and vertical precipitation on one side, and amounts of driving rain on the wall on the other.

We do not think, however, that we manage without laboratory research, where the forces applied should be as natural as possible. Laboratory tests will above all tell us if a construction is leaky or not, before we use it in practice.

The Norwegian test apparatus for driving rain is presented earlier, in Table 3 the wind forces frequently used during tests are compared with natural wind measured in Gothenburg, Bergen, Trondheim and Kinn. - Kinn is situated on a small island outside the Norwegian west coast. The onslaughts of driving rain at Kinn are severe, 1715 mm per year from the south in a free standing gauge.

Our artificial 33.5 m/sec. steady wind is too hard as an average also for Kinn, but the gust speed at Kinn could probably be about 49 m/sec., and the super pressure perhaps as great as 300 mmVS due to local conditions (cliffs, hills etc.).

In the apparatus test panels 160 x 160 cm can be submitted to driving rain from 5 to 60 l/m^2h and running water from 40 to 300 l/m h.

2. MAIN PRINCIPLES FOR JOINT DESIGNED TO WITHSTAND DRIVING RAIN

a) The rain should hit the joint sides and be led down as far out in the joint as possible.

b) The rain drops or the running water should never come into close contact with the wind barrier.

c) The intruded water should be shed out from joints at suitable intervals down the wall.

2.1 Joints between compact elements

In Fig. 7 the first principle is followed, but not the second. In this case the greater part (or all) of the wind pressure potential is acting across the joint sealing compound, the water will be pressed through the slightest slit between compound and adjacent joint side. If the joint is a horizontal one, the third principle is violated, the water will be trapped. Fig. 7 shows a one-step tightening, wind- and rain barrier are combined. The water tightness is solely dependent on the compound severely exposed to wind, rain, sun and temperature movements. The sealing might well be outflanked by water penetrating the adjacent materials. When the contact planes between sealing and joint material are wetted, the sealing might slip. Only the best and most expensive sealing materials will do in this case, and the joint sides usually need a careful pretreatment (priming) to ensure sufficient adhesion.

In Fig. 8 the first principle is followed, and provided that the air space behind the outer rain bar is connected with the outside air in one or both ends, also the second principle is taken into account.

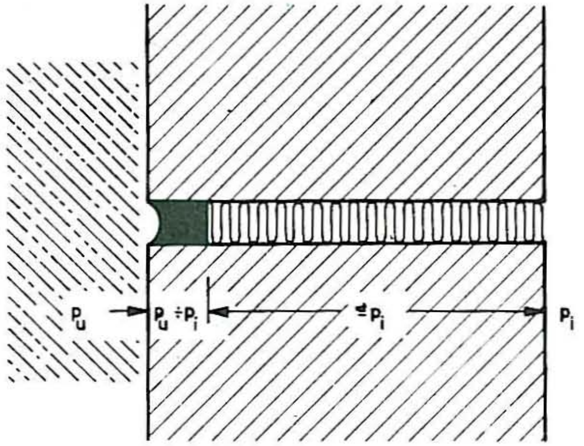

Figure 7. Wind- and rain barrier combined.

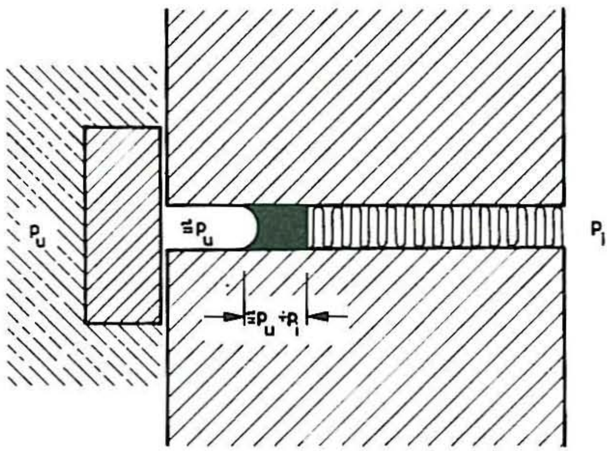

Figure 8. Rain- and wind barrier separated by an air space.

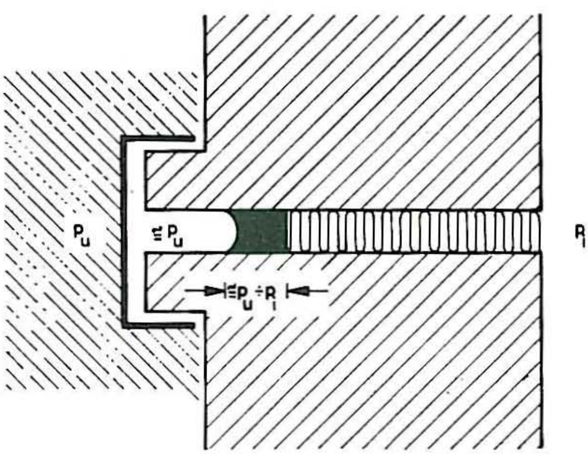

Figure 9. Closed joint with ribs.

The solution presented in Fig. 9 has protruding edges along the outer opening, the water will not easily run into the joint from the sides.

Both Fig. 8 and 9 show so called two-step tightening systems, where the rain bar is separated from the wind barrier, the sealing, by an air space. The joint sealing material is sheltered from sun, wind and rain and the greatest temperature movements. Obviously, this tightening system does not demand the most expensive joint sealers.

In Figs. 8 and 9 the joints are closed on the outside, the rain bar makes then 100 % safe against driving rain. Only vertical joints can be made in this way, the horizontal joints have to be selfdraining, i.e. they should be made more or less open against the weather side. Many vertical joints, f.i. between sash and frame in several window types, also have to be open because of the operation of the sash, (side-hinged, outswinging, horizontal pivoting etc.).

The importance of a rain bar in vertical joints with an outer opening = 15 ··· 5 mm.

Figs. 10 and 11 present 4 types of joints between concrete panels, i.e. the outer part of the joints. The inner concrete layer was of less importance in this case, the water had to be stopped before it entered the thermal insulation between the concrete layers.

The main results were that all joints, except No. 2, withstood the driving rain tests when the rain bar was used and the wind barrier consisted on neoprene +

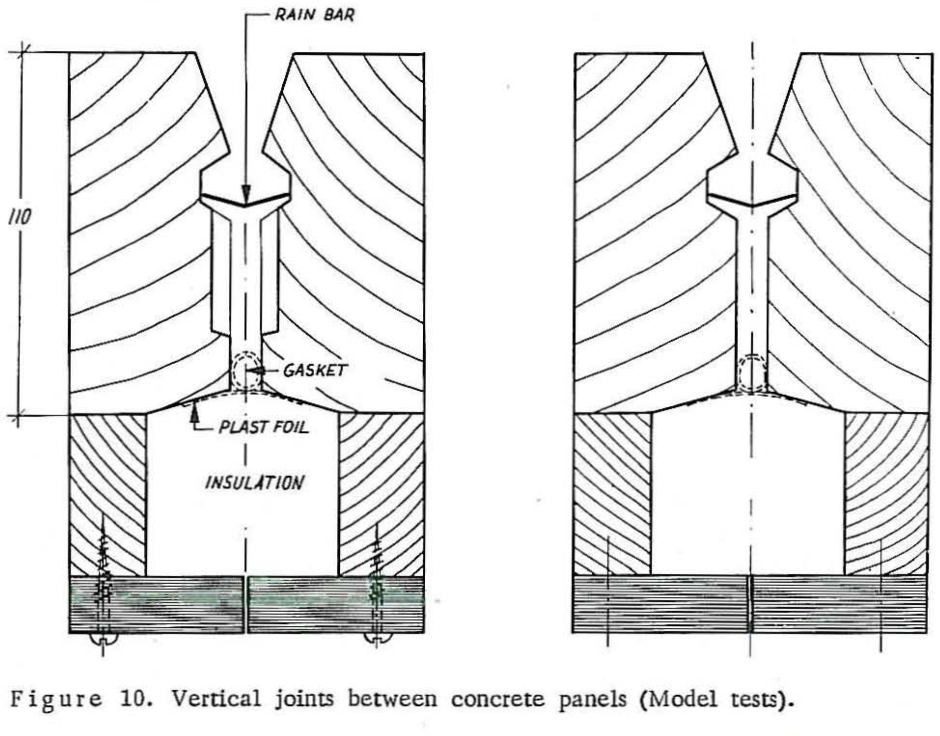

Figure 10. Vertical joints between concrete panels (Model tests).

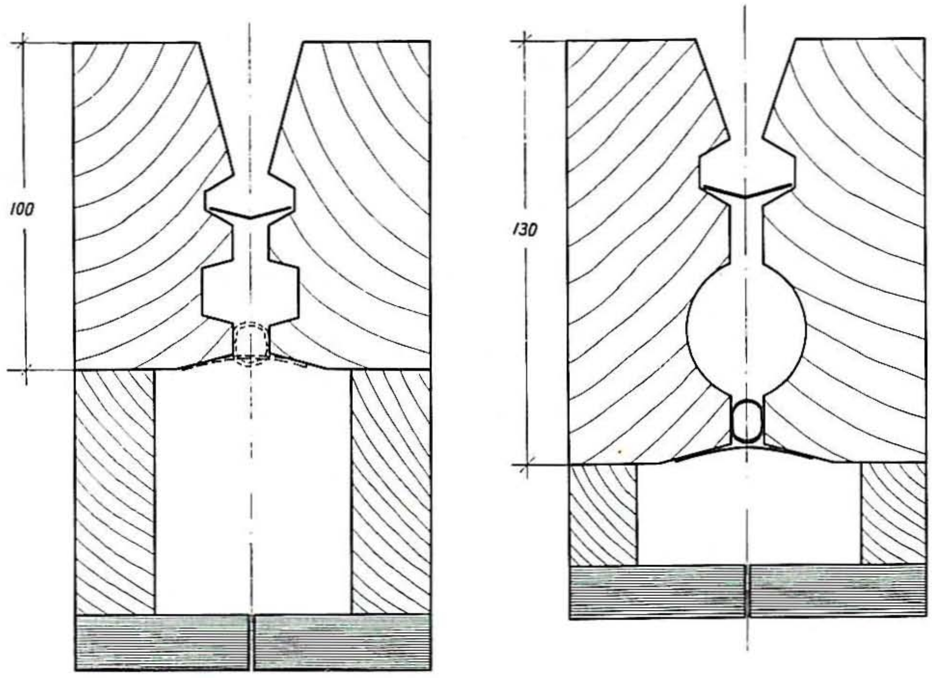

Figure 11. Vertical joints between concrete panels (Model tests).

rockwool or plastic foil + rockwool. (Stresses: v = 33.5 m/sec. driving rain 10 l/m^2h during 5 hours. No running water used).

All joints were penetrated by water even when the wind speed was reduced to 12 ··· 15 m/sec. and the rain bar omitted.

The rain bar alone kept the best 3 joints (with two grooves) dry nearly at their full lengths, while joint No. 2 was penetrated over its full height.

When the joints were regulated at 5 mm width, the penetrations still occurred as soon as the rain bar was removed.

A long series of tests with windows seems to confirm that the outer opening of vertical joints should not be greater than 3 to 4 mm in a rough climate. This narrow joint can not be obtained between panels of concrete, and hardly between sash and frame in large windows either.

Fig. 12 shows the concrete panel joints similar to our model joint No. 3. The system has been used for some years and no leakages are reported. The horizontal joint is provided with a drip nose, the opening is 20 mm high, the running water can not bridge the gap between upper and lower panel. The joint sides are, farther in, so wide apart that the joint can not be filled by water running down the wall. The height of the upper threshold of the lower panel is usually 7 cm. If the concrete joint sides should come into close contact with each other so that the water could fill the joint, 7 cm is in most cases a safe obstacle to water flow.

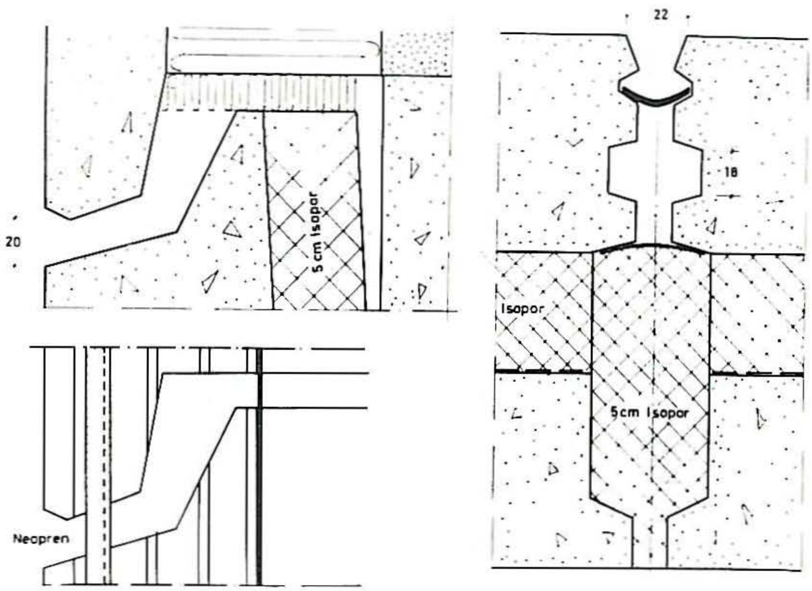

Figure 12. Concrete joints in practice.

It is of great interest to know how shallow open or closed vertical joints can be e made dependent on the shape of the joint sides. We have seen that the wind penetration itself was not the main cause of rain penetration, which occurred as well in rather wind tight joints (neoprene gasket + rockwool) as in wind leaking joints (rockwool alone) when the rain bar was not used.

To shed more light on the question, a research programme on vertical joints presented in Fig. 13 is made, and the model test panel is under construction. We hope that some results can be given at the symposium in Helsinki.

Open horicontal joints. The results from our model tests with open horizontal joints are presented earlier at a meeting in the CIB Large Panel Committee ans also in the CIB Rain Penetration Group. The results are repeated here because they show, like the results from vertical joints quoted above, that a bad air tightness is not always the reason of rain penetration, and absolutely not when the rain water is prevented from flowing into the wind barrier by a rain bar or by a deliberately designed drainage in the joint sides.

The very simple joint was made in wood, see Fig. 14. The opening (b) was varied between 0 and 15 mm, the slope (h) in steps 5 ··· 10 ··· 15 mm, and the wind penetration in steps 0.5 to 10.0 m^3/h per meter joint length under a wind speed = 33.5 m/sec. (Δp = 70 mm WC). The depth of the joint was always 45 mm plus the actual thickness of the gasket. The driving rain was 8 ··· 10 l/m^2h, in a few cases 60 l/m^2h was used to see if large quantities of driving rain were worse than great amounts of running water for a given opening of the joints. Running water amount was varied between 40 and 100 l/m.h.

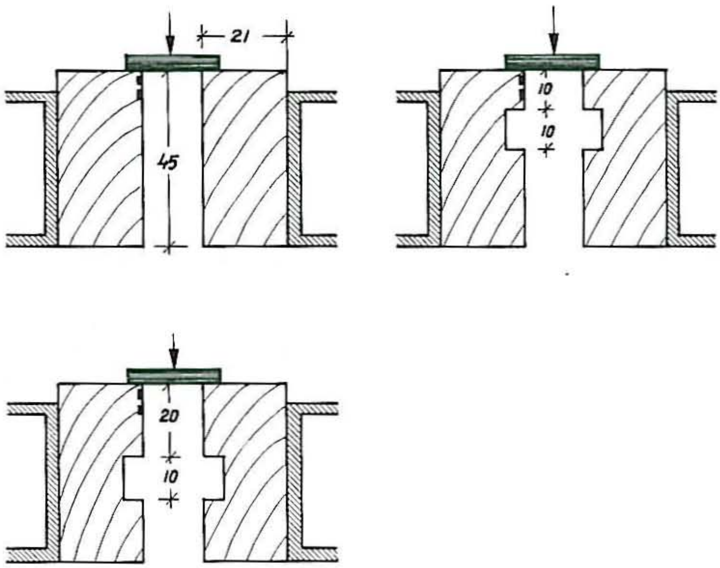

Figure 13. Vertical joints for model tests.

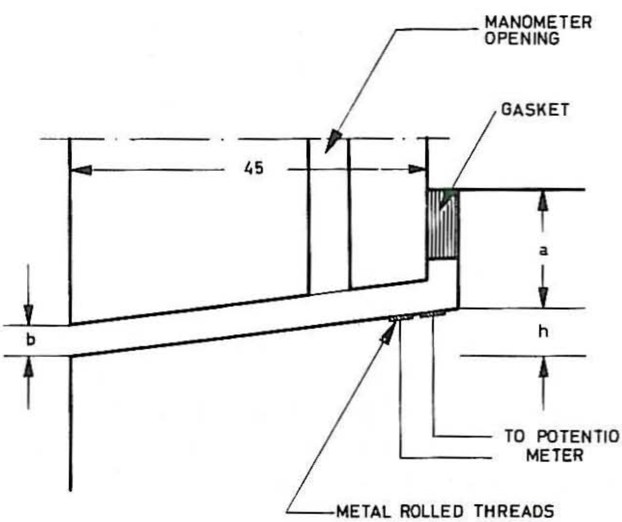

Figure 14. Horizontal, model joints in wood.

The main results said that in painted pine joint openings up to 4 mm were easily filled by running water, but that driving rain of 60 $1/m^2h$ did not penetrate the porous gasket in 4 mm joints when the air leakages were not greater than 4 $m^3/h.m$ joints. Oiled 4 mm teak-joints showed no penetration of water within 5 hours even when maximum stresses were applied (driving rain 8 ··· 10 $1/m^2$, running water 100 1/m h and air leakages = 10 m^3/h. meter joint). Joint openings from 6 to 15 mms were tight even when the air leakages were fixed at

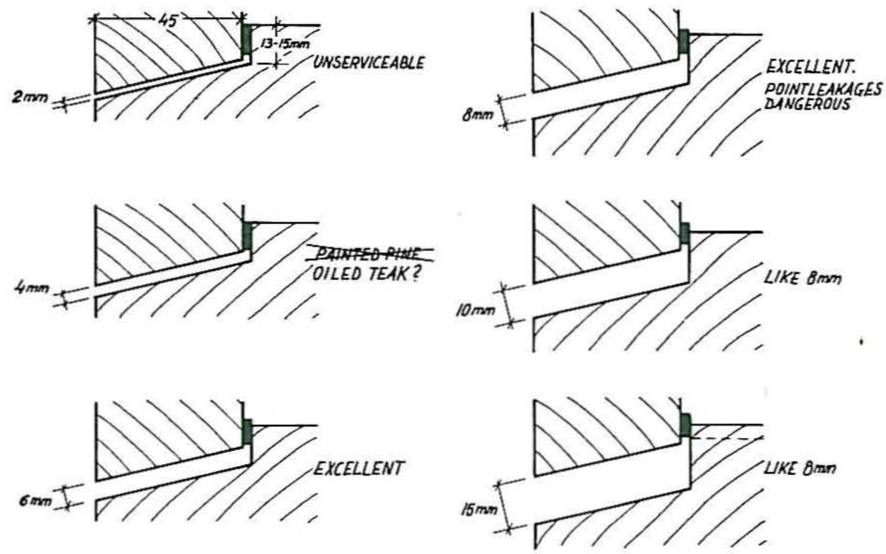

Figure 15. Main results from tests with joints in Fig. 14.

10 m^3/h.m joint under a super pressure of wind = 70 mm WC and max. driwing rain and running water were used. The good results concerning 4 mm teak joints to 15 mm teak (or pine) joints all depended on two factors: a) That the air leakages were not concentrated in points, and b) that the lower edge of the gasket was lifted 4 ··· 5 mms from the inner edge of the upper part, (a drip is necessary) see Fig. 15.

The results confirmed an old theory:
If the effect of the vertical joint is omitted, i.e. the rain is stopped far out in the vertical joint, the stresses on the horizontal joint are not very severe.

In practice air leakages are assumed to be smaller than 5 m^3/h and meter joint. According to the test results, the constructor of the leaking joint should be blamed rather than the sealing compound or the gasket.

Driving rain tests with simple horizontal joints in concrete.
Fig. 16 presents a vertical section. Two joints had very smooth surfaces, they were cast against a plastic laminate. These surfaces prevented penetration much better than normal surfaces cast against planed wood, but only when:

a) The joints were > 4 mm, or
b) the joints were impregnated with a silicone.

Penetration occurred when:

a) The joints were $\leq$ 4 mm and
b) the joint surfaces were not impregnated.

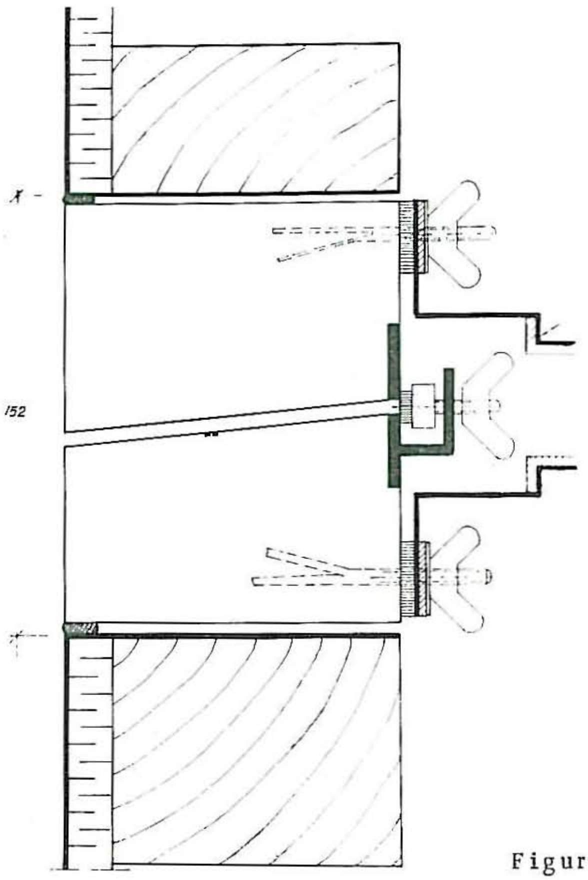

Figure 16. Model joints in concrete.

The stresses were: Wind 21 m/sec. (F = 9), running water 40, 70 or 100 l/m. h. Driving rain was not used because we knew it was not important when the joint was like or more narrow than 6 mm. The air leakage was only 1 m^3/ per meter joint under a super pressure = 30 mm WC.

It is evident that openings less than 4 mm should not be used when the design is so simple as in Fig. 16. If 4 mm's can not be avoided in certain cases, the slope should be at least 1:5 and the depth for smooth surface joints be at least 7 cm, and for normal surfaces at least 9 cm.

Conclusions: It is not difficult to design rain-tight horizontal joints either if the water is prevented from running in via the vertical joint.

Examples from practice:

Bad experience is obtained with joints shown in Fig. 17. The wind barrier consists of mortar, and partly by jute. The mortar has cracked, the joints are leaking rather much because the water penetrating through the vertical joint can not be drained out in the horizontal joint.

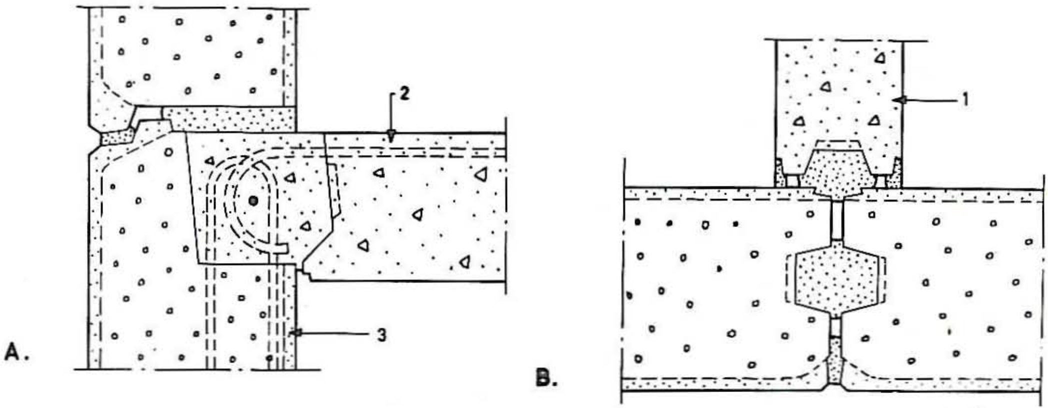

Figure 17. Bad joint design. Mortar in outer part of horizontal joint prevents draining.

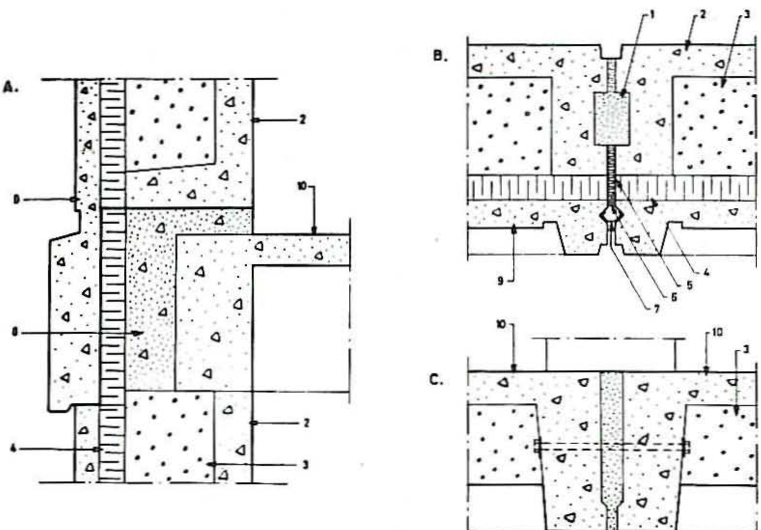

Figure 18. Good design of joints between concrete panel.

Good experience is had with joints presented in Fig. 18. The wind barrier is here a neoprene gasket well hidden from rain, sun and temperature movements by the rain bar and the air space.

THE MAIN PRINCIPLES FOR JOINT DESIGN USED IN EXISTING WINDOWS

A. Wooden windows

1. The joints are open against the outside.

Example: Norwegian Standard 1463. The driving rain drops hit the 2 ··· 3 mm narrow outer opening and are slowly led down because they cling to both joint surfaces. When the joint is made bigger than 3 mm, small vertical grooves near the outer opening do not work, the rain drops can pass them before hitting the joint surfaces. The standard's great groove is more effective, it is situated far in and is sheltered from direct drop hits. At the lower end of the sash, the vertical groove is flush with the outer threshold of the sill. The wind barrier, the gasket, is well hidden from driving rain and running water, and also functions as a rather fine vapour barrier. The joint between sash and sill has a design similar to our simple model test joint, but is more accentuated as to water stops.

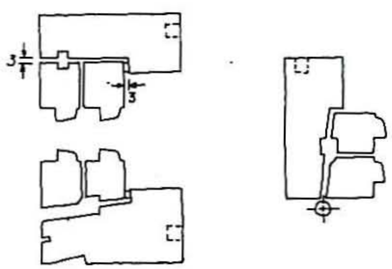

Figure 19. Norwegian Standard 1463.

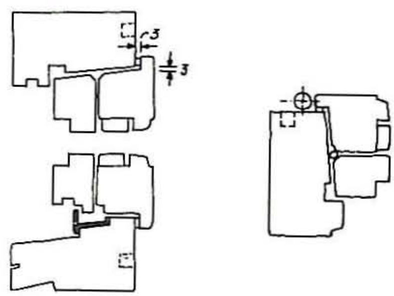

Figure 20. Norwegian Standard 1464.

2. The joints are closed on the outside.

Example: NS 1464.

When the joints on the top and on the sides of the sash are sheltered against direct hit from driving rain, the drainage groove can be placed just inside the overlap, see Fig. 20. At the bottom the drainage groove is formed by the aluminium profile.

A few years ago this window (formerly NS 764) was not recommended for use in exposed areas, water leakages occurred before the gasket and the metal profile were used. Even now the window manufacturers sometimes forget to make the necessary drain holes in the outer flange of the metal profile, or they use too small drills. Necessary diametre is at least 5 ··· 6 mm.

3. The window type preferred by many Norwegians.

In spite of wind- and raintight standard windows, most Norwegians do not want them, "windows so open against the weather as NS 1463 can not be tight". The pre-

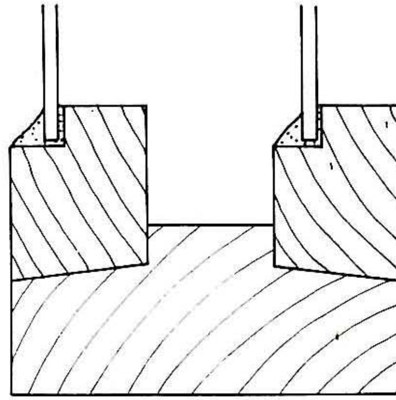

Figure 21. Very bad joint design.

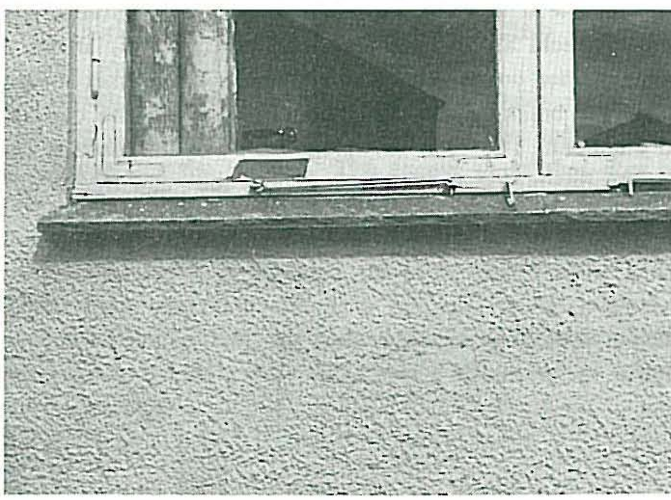

Figure 22. Lower sash always wet because of narrow bottom joint.

ferred type is presented in Fig. 21: it can only be shut all right in dry summer weather, and sill and lower sash are always wet. Maintenance costs are high, and frequent repainting does not prevent dry rot, see Fig. 22. In winter time the condensation on outer pane is severe.

4. Tightness of assemblages, especially of the lower frame corners.

A very important thing is not at all mentioned in the Norwegian Window Standard: the tightness of the lower frame corners. In the recent years some window manufacturers have claimed that frame corners should be nailed, not supported with screws or glued, to enable the carpenter to form the windows after the wall openings, as he will do, anyway. - This is no proper solution of a problem, it is impossible to keep the assemblages water tight if a waterproof glue is not used, and the taps do not fit exactly.

During recent years very bad corner leakages have been discovered, too late. The wooden frame work below the window is destroyed by fungi, in some cases the deteriorations were so bad that greater parts of the wooden walls had to be removed.

B. Metal- and plastic windows

1. Metal windows.

Corrosion-proof window profiles are expensive, and their thermal conductivity is so great that a thermal insulation must be used either on the inner side or between two separated profiles. In the last case, the construction usually becomes both heavy and expensive, and the constructor is compelled to save metal. The window becomes shallow if he can manage with simple mountings, etc. He must, however, prevent the cold air to cool down the inner profile, if not the breaking of the cold bridge further out is of less importance. The gasket should, accordingly, be connected with the break of the cold bridge, i.e. near the outside, minimizing the outer, cold chamber. The type of window that fits this pattern best, seems to be the side-hinged, inswinging type, because both top- and side joints are sheltered against driving rain, see Fig. 23. Here the distance between gasket and outer frame flange can be reduced to 10 ··· 12 mm.

2. Windows of plastic.

The cold bridge problem is avoided when the plastic profiles are reinforced by glas-fibres or made by means of a steel core (tube) encircled by a thick plastic

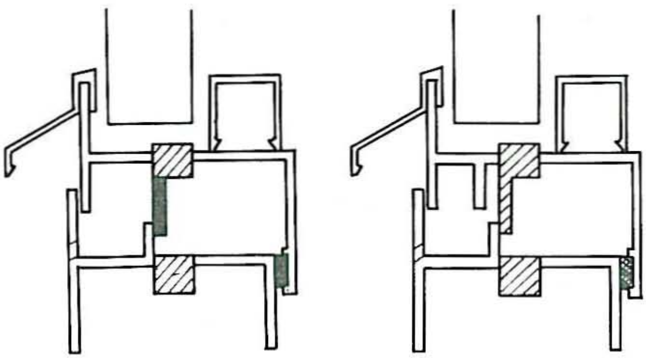

Figure 23. Sketch of bottom joint in metal window. Inner gasket can be omitted.

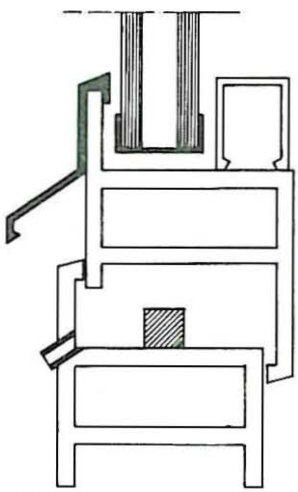

Figure 24. Sketch of plastic window.

coat. The gasket can be placed as far towards the inner side as possible, see Fig. 24.

NB! The water drip nose on the lower sash can never be omitted in shallow windows of metal or plastic when the sash is side-hung and swings inwards. The drainage of the sill must not be forgot.

Outside window casing

Norwegian traditional casing on the top of the windows was a water board, a metal sheeted drip nose, see Fig. 25.

At present the architects seem to forget the purpose of the drip nose, and make casings as presented in Fig. 26. The water previously led away form the dangerous point, the top joint between sash and frame, can now run into it, fill it and come into contact with the gasket. The worst leakages occur when the side joints go straight through, without any other obstacle to intruding water than rebates and gasket, f.i. tall, horizontal pivoting windows with trailing gaskets placed as multistorey panels, see Fig. 27.

Due to lack of drip noses on the sills, the water passes the vertical rebates (grooves) in the top corners, and keeps contact with the gasket to bottom sash corner where it penetrates the window. The excess water that does not come into our rooms, runs further downwards without being led out by drip noses. Water is therefore penetrating far into the joint in every top corner.

Recessed, horicontal bands of windows are to be preferred on severely exposed high-houses rather than vertical bands. It is essential to break up the running water current or film, to lead it out from the wall surface as droplets.

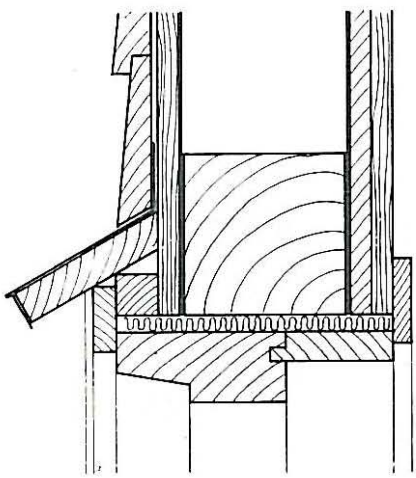

Figure 25. Metal on water boards above and below window.

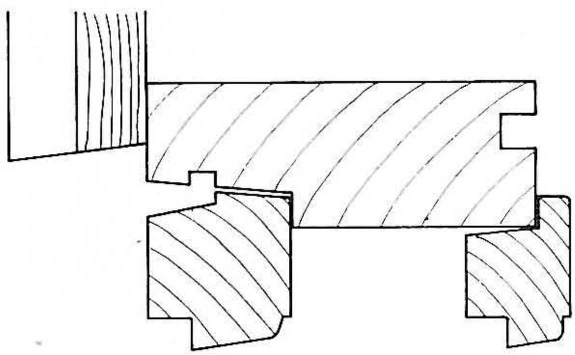

Figure 26. Wood panel ends cover the head jamb.

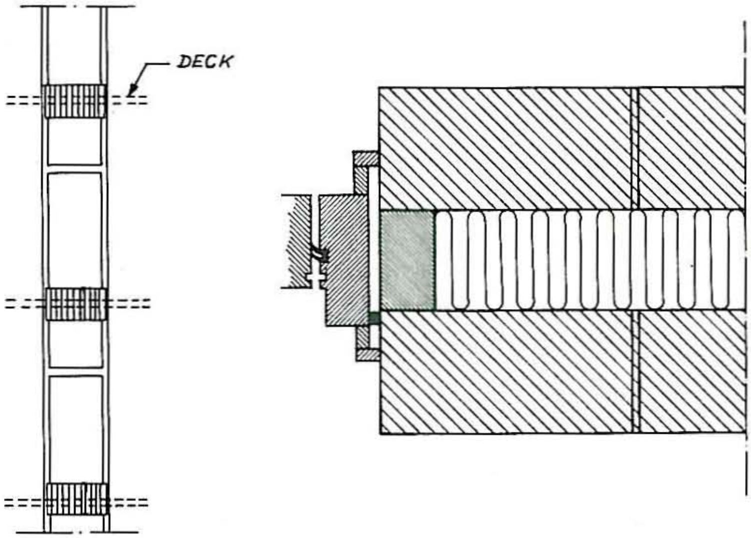

Figure 27. Tall vertical panels of windows and spandrels without horizontal protrudings for drainage.

Figure 28. Stone plate sheathing cast against backwall of concrete is no good solution in exposed areas.

2.2 Joints in sheathings

1. Unventilated sheathings.

Plates of stones cast to concrete walls usually get stains and frequently loosen when the water penetrates the joint mortar and freezes, see Fig. 28.

On wooden boards with the flat, inner surface in contact with building paper, the paint peels off after a year or two, the boards on the weather side of the building are always wet.

The insulated hollow masonry wall is something between the ventilated and the unventilated sheathing. The cavity with insulation of mineral wool is ventilated and drained by means of open, vertical joints in the lowest course of bricks, see Fig. 29. If we have many open joints, the insulation properties will be reduced. The wind will, we know, try to move straight through the wall. If the inner leaf is rather airtight, the wind speed within and along the cavity will be far greater than across it because great suction occurs around the corners of the building where the air is sucked out through the vent-holes. In exposed areas the trend is therefore to use as few vent-holes as possible.

The wooden "blind-frame" connecting inner and outer brick leaves sometimes get wetted by water penetrating the outer leaf. In one case a metal sheeting of both "blind-frame" and window frame seems unavoidable, see Fig. 30.

2. Ventilated sheathings.

As a principle the ventilated sheathing is working like our 2-step tightened joint both when the sheathing has open or closed joints leading from the exterior to the air space behind.

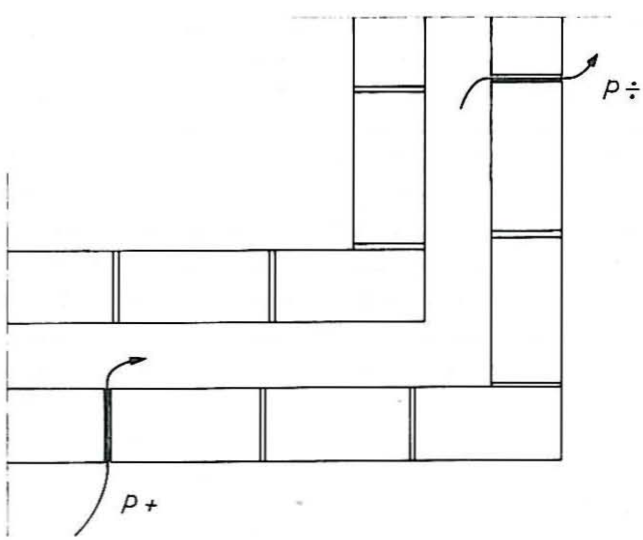

Figure 29. Cold air penetrates the thermal insulation because of pressure potential over a corner.

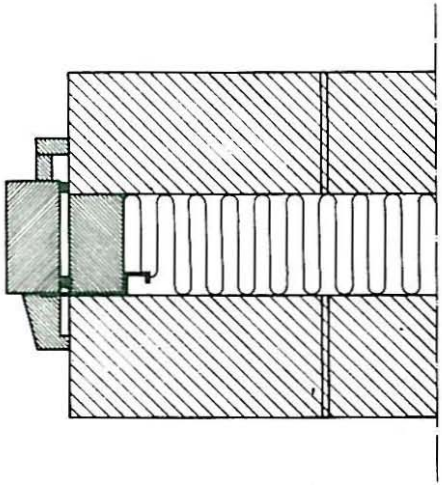

Figure 30. Metal sheeting on frame and on "blind-frame".

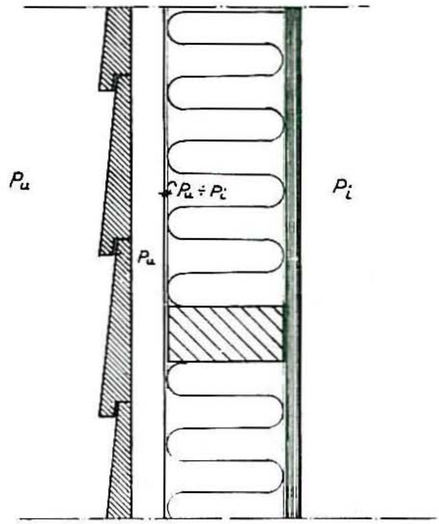

Figure 31. Ventilated sheathing on a wooden wall.

In a wooden frame wall the wind-barrier is formed by building paper on the outside of the studs. Within the air space between sheathing and wind-barrier, the air pressure will as a rule follow the variations of the super pressure on the outside, and the more rapid the more openings there are in the sheathings.

Because of this some constructors seem to believe that the number and size of the open joints have to be great. They forget that raindrops have speed and weight. It is evident that a sheathing without open joints offers the best resistance to driving rain provided that the air space is connected with the outside air by openings sheltered from the rain. But what about water transport through covered joints in a sheathing if they are filled with water? (see Fig. 31). Our model tests showed that the air leakages had to be very great and concentrated if they managed to tear off water from surfaces. In the sheathing case the water will run down on the inner side of the sheathing and stick to it, it will not jump across the air space. It can, however, be led over to the back wall when the drainage is bad, f.i. via door- or window frames. A wind pressure potential across the air space is therefore not the reason for water penetration through the wall when the sheathing has closed joints. A faulty design of drainage and/ or holes in the wind barrier are usually the main cause, the water simply flows into the wall by its own gravity.

This is a warning to constructors who are fond of big, open joints, without regard to depth of the air space between sheathing and wind barrier. In the Scandinavian countries, the snow does not diminish the open-joint problem, see Fig. 32. The photo is from our test house in Trondheim, where the inner wall

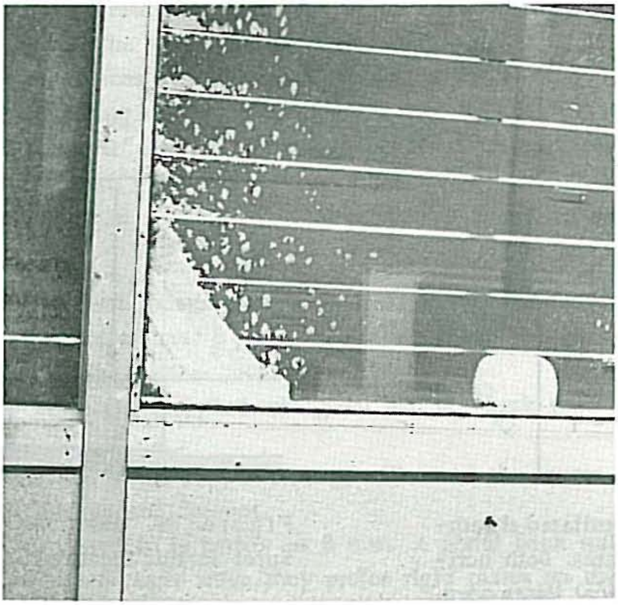

Figure 32. Snow penetration through open joints in sheathings of wood boards.

consists of glass. The vertical, open joints vary from 10 to 3 mm, the horizontal ones are all 7 mm. The thickness of the wood boards is 20 mm, the air space is 21 mm (1 in. planed).

And still we know that we can use open joints both between wood boards and in sheathings of asbestos cement or metal plates. The question is then: How big can we make the open joints in different sheathings for given depths of the air space?

Provided that we know how to drain out water that has come into the air space, the question is: How much water can hit the back wall via the open joints, and how much water can be absorbed by the wall without doing any harm? The greater the amounts, the harder claims must be laid on the back walls water repellent ability and on its frost resistance: - It is necessary to measure the water amounts on the back wall.

Suspended sheathings of stone plates.

NBRI has made some work on ventilated sheathings of stone plates, dimensions 70 x 70 x 2 cm, with open vertical and horizontal joints, see Fig. 33. The back wall was made of glass to see where and how the water spouts across the air space and hits the back wall.

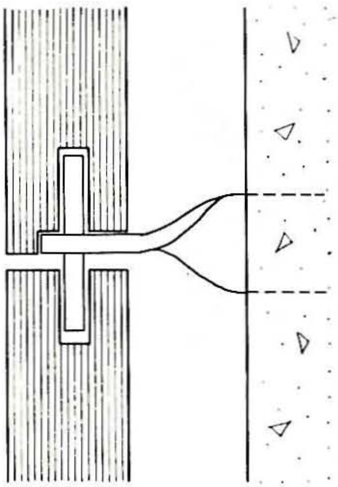

Figure 33. Ventilated sheathing of stone plates. Both horizontal and vertical joints open.

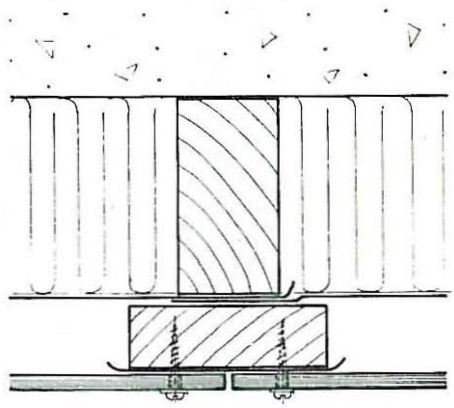

Figure 34. Horizontal section of Super Eternit sheathing.

The driving rain amount has been 10 l/m^2h, running water 40, 70 or 100 l/m.h., wind speed either steady 33.5 m/sec. (70 mm WC) or gust speed 14 ··· 42 m/sec., Beaufort 10.

The results are valid only for 2 cm thick plates, usual thickness is 3 cm. Water amounts hitting the back wall should be reduced when the thickness of the stone slabs is increased.

For 2 cm plates it seems that:

a) Joints with max size of 5 mm will withstand the rough climate on the Norwegian west coast.

b) Joints of 7 mm will be all right where the wind speed never exceeds 33 m/sec.

c) Joints of 10 mm are too big.

d) Great amounts of water run down on the inner sheathing surface, the air space should be properly drained.

e) In practice 7 mm joints, 3 cm slabs and 3 cm air space are used, the back wall can be light weight concrete or concrete. According to the test results, practice is all right.

Super Eternit ("Malmex") plates mounted on 50 mm vertical lattices and with open horizontal joints.

NBRI has tested the sheathing both in the laboratory driving rain apparatus and on existing buildings in Gothenburg and in Bergen. As shown in Table 2 both towns have plenty of rain and wind.

The Swedes want narrow air spaces, for instance 8 mm, and use Internit-plates as the wind barrier on the outside of the wood studs, and 50 x 8 mm vertical strips of Internit as lattices.

In Norwegian mounting wooden lattices 1 in. to 1 1/2 in. x 2 in. are frequently used, and the "back wall" is as a rule consisting of an impregnated building paper covering the wood studs.

Fig. 34 is a horizontal section of the Super-Eternit sheathing and the back wall.

The main results are:

1) The laboratory tests showed that very small amounts of water hit the back wall when the joints were max. 5 mm and the air space $\geq$ 8 mm, even in gusts of 42 m/sec.

The buildings in Bergen and Gothenburg all had dry back walls when 5 mm joints were used.

The results thus tell us that the sheathing will stand the severe stresses in exposed areas in Norway and Sweden.

2) When the air space is as narrow as 8 mm, a plane back wall is necessary, i.e. that the Swedes are right when they prefer rigid plates on the studs.

3) When the air space is 3/4 in. or thicker, a building paper can cover the studs if fire problems are not taken into account, and the building paper is not pressed out against the sheathing by the thermal insulation.

At last a photograph from our new test house in Trondheim where the Super Eternit sheathing type B is mounted on the northwest wall. In Trondheim driving rain and sleet from west and northwest are a nuisance by Christmas time, when the sun visible hours are few and the drying possibilities bad. If the sheathing works well here, it can be used safely in most parts of Norway.

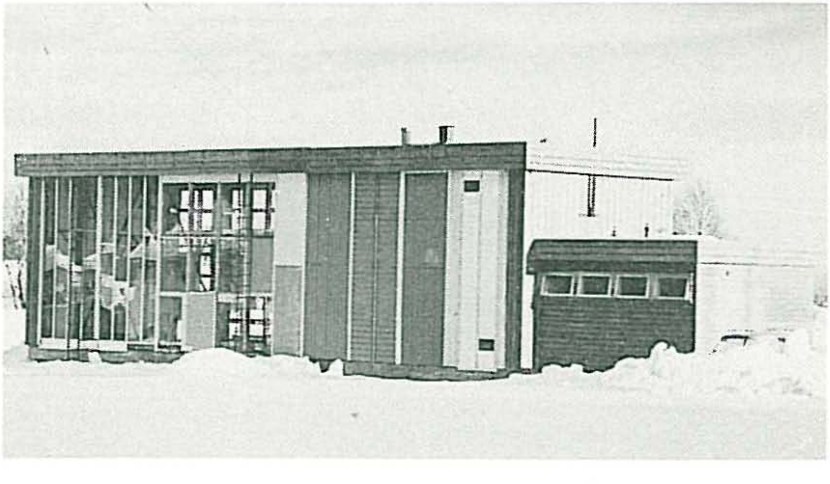

Figure 35. Exterior of test house in Trondheim.