POSTINSULATION ON ROOFS USING WEATHER EXPOSED MINERAL WOOL

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ABSTRACT

Outer postinsulation on roofs using weather exposed mineral wool shows, that glasswool and rockwool have good thermal qualities to this purpose. The aim of this work is to make a pilot investigation of the weather exposed mineral wool used as postinsulation on roofs. Measurements of 9 different weather exposed roof sections have been carried out during a 2 years period. The postinsulation consists of 100 mm mineral wool mounted on top of a corrugated steel sheet roofing above a loft room. The roof pitch is 35°. The loft room is thermal insulated with 100-150 mm expanded polystyrene.

The measurements show that the freely postinsulated roof in average insulates just as well as the same roof covered with roofing felt on the top of the insulation. The economics for the postinsulation are favourable, if the roof from the beginning is slightly insulated and calls for maintenance of the surface.

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SUMMARY

Outer postinsulation on roofs using weather exposed mineral wool shows, that glasswool and rockwool have good thermal qualities to this purpose. The aim of this work is to make a pilot investigation of the weather exposed mineral wool used as postinsulation on roofs. Measurements of 9 different weather exposed roof sections have been carried out during a 2 years period. The postinsulation consists of 100 mm mineral wool mounted on top of a corrugated steel sheet roofing above a loft room. The roof pitch is 35^{o}. The loft room is thermal insulated with 100-150 mm expanded polystyrene.

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INTRODUCTION

Outer post insulation on roofs with freely exposed glasswool and rockwool is very interesting, because mineral wool shows good thermal qualities to this purpose. The idea of insulating the buildings with freely exposed mineral wool is based on observations of the good old, and purposefull Danish straw roof. This roof is constructed with freely exposed straws with no protection at all to the weather, and it has a well documented life of more than 20 years. The open fibre structure in connection with the influence of moisture therefore seems to be a reasonable technical solution.

The aim of this work is to make a pilot investigation of the weather exposed mineral wool used as additional insulation on roofs. The qualities of the postinsulation are illustrated by measurements of the U-values ($W/m^{2o}C$) on 9 roof sections.

The postinsulation consists of 100 mm mineral wool mounted on top of a corrugated steel sheeting. The loft room under the steel sheeting is insulated with 100-150 mm expanded polystyrene.

The roof sections are built and placed on the area of the Technological Institute, Copenhagen, Denmark.

OUTER POSTINSULATION ON ROOFS USING WEATHER EXPOSED MINERAL WOOL

The roof which is postinsulated from the outside with mineral wool is called the upside-down roof, the inverse roof or the protected membrane roof. The test roof sections are shown in figure No. 1.

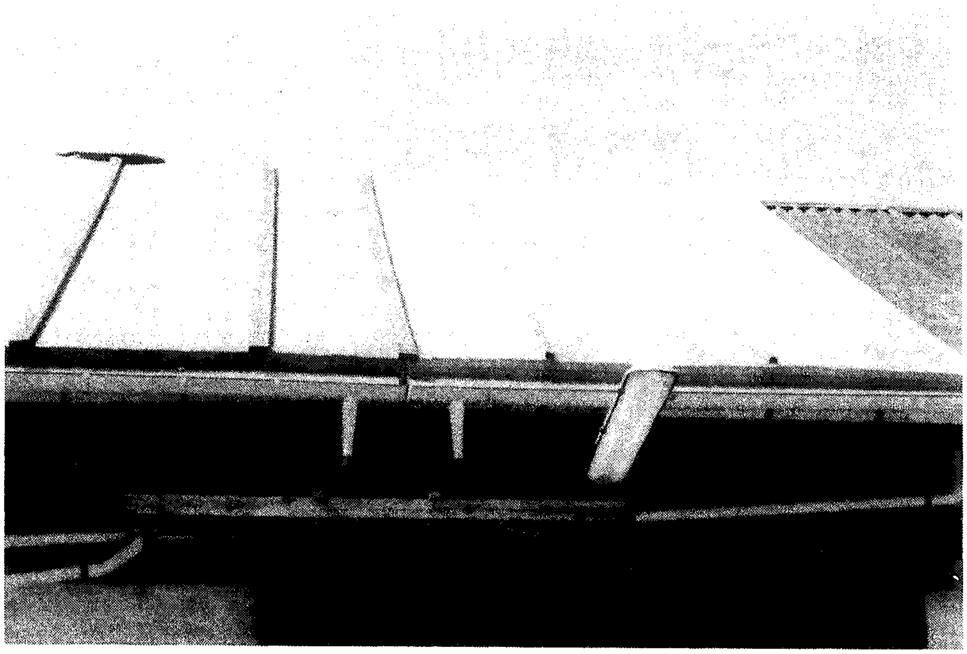
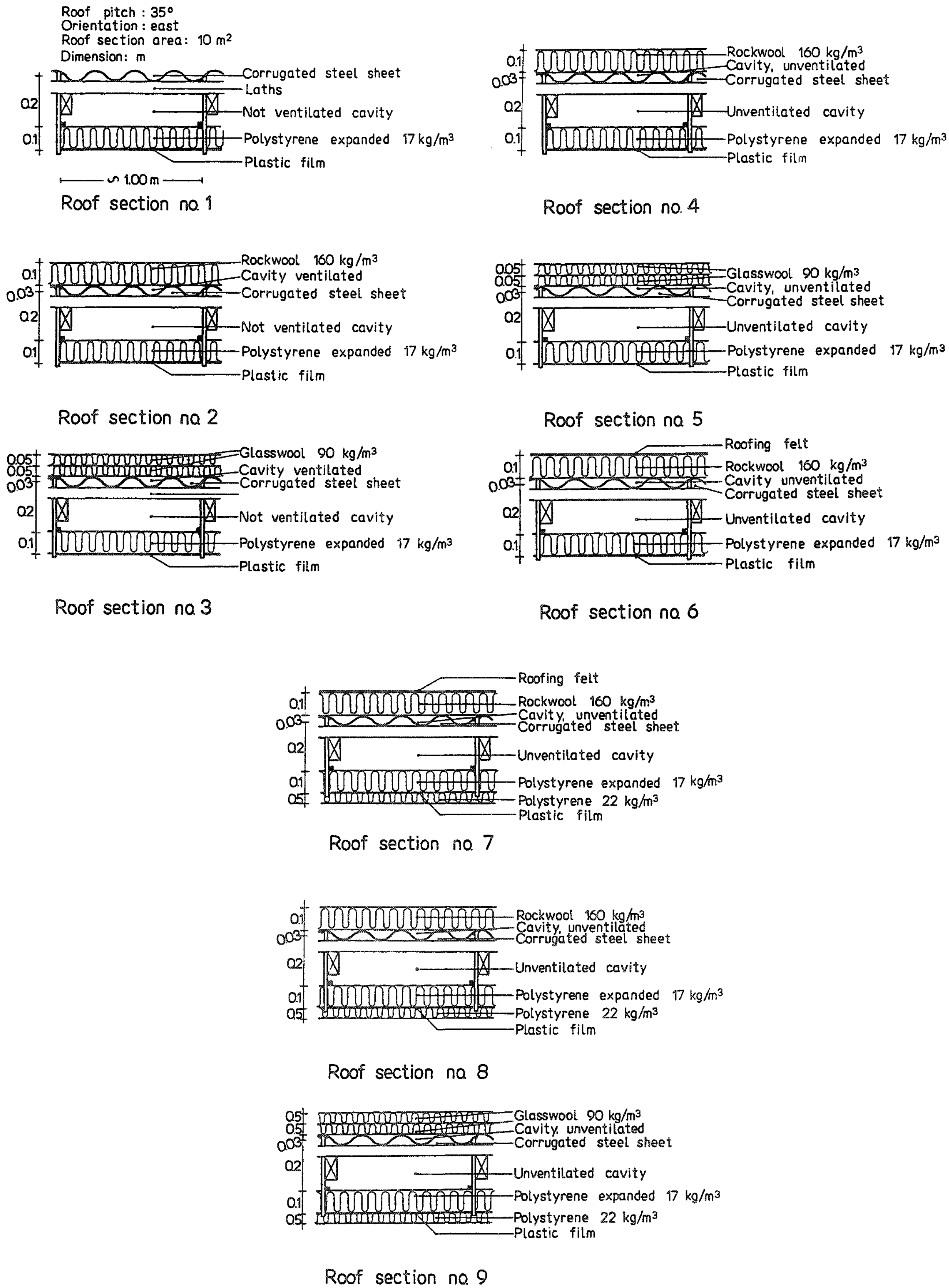


Figure No. 1. The test roof sections at the Technological Institute, Copenhagen, Denmark.

The 9 test roof sections are shown in figure No. 2.



FIGUR NO 2
THE CONSTRUCTION OF THE 9 TEST ROOF SECTIONS.
THE MINERAL WOOL IS BATTS WITH A SIZE OF 1.2 × 2.4 m²

On those 9 roof sections the U-values ($W/m^2\ ^oC$) were measured during the winter 1982/83 and 1983/84.

The roof sections No. 2 and 3 are naturally ventilated with outer air between the mineral wool material and the corrugated steel sheets. The area of ventilation is placed at the gutters of the roof. See figure No. 1. At the ridge of the roof there is no ventilation.

The roof sections No. 4 - 9 are not ventilated under the mineral wool.

All steel sheets are painted black on the inner surfaces. The air tightness of the plastic film is controlled by measurements with tracer gas.

MEASURING EQUIPMENT AND THEORY

The measured U-values are derived by calculation from the measured values for the heat flow through the actual roof sections. The heat flow is measured by means of heat flow meters. The flow meters consist of a 80 mm thick plate of expanded polystyrene (17 kg/m^3) with thermo-couples on the two parallel faces. On each face a 10 mm thick plate of polystyrene is glued. This gives a total thickness of the heat flow meter construction of 100 mm. The heat flow area is approx. 0,7 m^2. The position of the heat flow meters is shown in figure No. 2. Each roof section has two heat flow meters.

The U-values of the roof sections are calculated as follows

$$U = \frac{\lambda \cdot \Delta t}{d \cdot (t_i - t_u)}$$

where

U - the heat flow ($W/m^2\ ^oC$)
λ - the measured thermal conductivity ($W/m\ ^oC$) for the dry polystyrene in the heat flow meters (ASTM C 177)
d - the thickness (m) of the polystyrene in the heat flow meter
Δt - the measured difference in temperature (^oC) over the layer of polystyrene
t_i - the indoor air temperature (^oC) at each of the flow meters
t_u - the outer air temperature facing north and in the shade (^oC).

The indoor air temperature is approx. 20^o Celcius. All the data of temperatures are collected electronically for every half hour.

The systematic mean error for measuring the U-value for each roof section is estimated to approx. ± 5%.

RESULTS

In table I the average measured U-values are listed. The weather in the measuring period is also shown by daily average values for the whole period. The U-values are listed for the night, 6 hours, from 0 - 6 A.M. and for the day and night, 24 hours. The night values show the behavior of the construction when no radiation from the sun occurs.

In table II the average measured night U-values are compared with the calculated U-values of the dry construction. The calculation method is described in {1}.

Table I. Average measured U-values. The data of the weather are shown as average values for the measuring period.

Roof section No.	Period No.	Period	Length of period (days)	Measured U-night ($W/m^2{}^oC$)	U-values U-day & night ($W/m^2{}^oC$)	Rainfall (mm/day)	Sunhours (h/day)	Windspeed (m/s)	Outdoor air temp. (^oC)
1		14/2-7/3 1983	22	0,326	0,280	1,0	4,2	3,1	0,6
2	1	"	"	0,153	0,156	"	"	"	"
3		"	"	0,178	0,174	"	"	"	"
1		21/3-8/4 1983	19	0,330	0,237	4,3	4,5	3,6	3,6
4	2	"	"	0,142	0,146	"	"	"	"
5		"	"	0,168	0,163	"	"	"	"
6		12/12-17/1 1983/1984	37	0,217	0,212	3,0	1,9	5,0	2,3
4	3	"	"	0,163	0,166	"	"	"	"
5		"	"	0,190	0,191	"	"	"	"
7		16/3-20/3 1984	4	0,133	0,111	0,05	9,3	2,8	-0,9
8	4	"	"	0,109	0,105	"	"	"	"
9		"	"	0,124	0,108	"	"	"	"

Table II. The measured U-values in relation to the calculated U-values. The calculated values are based on the measured thermal conducitivites for the dry materials. (ASTM C 177).

Roof section No.	Period No.	Measured U-values U_{night} $(W/m^2\ ^oC)$	Calculated U-values $U_{calculated}$ $(W/m^2\ ^oC)$	$U_{night}/U_{calculated}$
1		0,326	0,314	1,04
2	1	0,153	0,159	0,96
3		0,178	0,148	1,20
1		0,330	0,314	1,05
4	2	0,142	0,159	0,89
5		0,168	0,148	1,14
6		0,217	0,158	1,37
4	3	0,163	0,159	1,03
5		0,190	0,148	1,28
7		0,133	0,128	1,04
8	4	0,109	0,128	0,85
9		0,124	0,121	1,02

The conductivities for all the layers of material in the calculations are the dry measured thermal conductivities at the actual mean temparatures in the construction.

The inner surface thermal resistance is estimated to 0,13 $m^2\ ^oC/W$. The external surface thermal resistance is estimated to 0,04 $m^2\ ^oC/W$. The thermal resistance of the cavity between the polystyrene and the corrugated steel sheets is estimated to 0,20 $m^2\ ^oC/W$, 2 .

The resistance of the cavity between the corrugated sheets and the mineral wool is estimated to 0,19 m^2 $^oC/W$.

In table III the relative average measured U-values are shown. In this table it is possible to compare the different roof sections with each other.

Table III. The relative average measured U-values.

Roof section No.	Period No.	Measured U_{night} W/m^2 ^oC	U-value $U_{night\ and\ day}$ W/m^2 ^oC	Remarks
1		0,326	0,280	
2	1	0,153 (0,173)	0,156 (0,124)	$(U_1 - U_2)$
3		0,178 (0,148)	0,174 (0,106)	$(U_1 - U_3)$
1		0,330	0,237	
4	2	0,142 (0,188)	0,146 (0,091)	$(U_1 - U_4)$
5		0,168 (0,162)	0,163 (0,074)	$(U_1 - U_5)$
6		0,217 (1,00)	0,212 (1,00)	(U_6/U_6)
4	3	0,163 (0,75)	0,166 (0,78)	(U_4/U_6)
5		0,190 (0,88)	0,191 (0,90)	(U_5/U_6)
7		0,133 (1,00)	0,111 (1,00)	(U_7/U_7)
8	4	0,109 (0,82)	0,105 (0.95)	(U_8/U_7)
9		0,124 (0,93)	0,108 (0,97)	(U_9/U_7)

During rainfalls we measured the amount of water coming through the mineral wool by means of a double gutter. The results are that 2 - 6% of the falling rain gets down through the joints of the mineral wool slabs.

The water content in the rockwool material was measured after a day with 8 mm of rain. (March 7th 1983). The amount of water was 0,35% by weight. The distribution of water in the sample is shown in table IV.

The water contents were measured by weighting and drying the samples of material.

Table IV. The distribution of water in the rockwool.

Sample of rockwool	Depth (m)	Water distribution (%)
Top	0,014	23,1
	0,028	15,4
	0,042	12,8
	0,056	12,8
	0,070	12,8
	0,084	15.4
Bottom	0,100	7,7
		100

DISCUSSION OF THE RESULTS

The influence from the weather of the upside-down roof sections is difficult to assess, but it is obvious that the falling rain does not have a significant influence on the U-values. Observations in the field confirms this point. Samples of the mineral wool have been investigated and found allmost dry. Only the upper slice of the slabs was wet in a depth of approx. 5 - 10 mm.

The night values are interesting because the radiation from the sun does not effect the heat flows in the roofs. The day and night values are interesting because they show the effective U-values of the roof sections for the specific location in Denmark. Period No. 1 gives the improvement of postinsulating roof section No. 1 as section No. 2 and No. 3.

In table V the insulating qualities of the materials are shown.

Table V. The thermal qualities of the postinsulation from roof section No. 1 to No. 2 and No. 3. (Period No. 1). The equivalent conductivity is related to the thickness of the mineral wool.

Postinsulation material	Thickness (mm)	Resistance (m^2 $^oC/W$)	Equivalent conductivity (W/m^oC)	Remarks
Rockwool	100	3,468	0,029	night
		2,839	0,035	day and night
Glasswool	100	2,550	0,039	night
		2,176	0,046	day and night

Table VI shows for period No. 2 the improvement of postinsulating roof section No. 1 as section No. 4 and No. 5.

Table VI. The thermal qualities of the postinsulation from roof section No. 1 to No. 4 and No. 5. (Period No. 2).

Postinsulation material	Thickness (mm)	Resistance (m^2 $^oC/W$)	Equivalent conductivity (W/m^oC)	Remarks
Rockwool	100	4,012	0,025	night
		2,630	0,038	day and night
Glasswool	100	2,922	0,034	night
		1,916	0,052	day and night

Closing the natural ventilation under the mineral wool gives a decrease of the U-value by 5 to 7%.

If we compare the roof sections No. 6, 4 and 5 we see that the upside-down roof sections insulates 10 - 22% better than the conventional roof section covered with a bitumineous roofing felt.

When the inside loft insulation is increased by a 50 mm thick expanded polystyrene, the results show a net improvement by 3 to 5% of the U-value of the sections 8 and 9 of the upside-down roof compared to section 7.

In relation to the above mentioned measurements we have to take in account the size of the systematic errors by measuring the U-values. The mean errors are approx. $\pm$ 5% but the maximum errors might be up to $\pm$ 10 - 15%. The size of those errors shows, that the conclusions directly made from the measurements must be conservative.

ECONOMICS

The cost per m^2 for postinsulating the roof consisting of corrugated steel sheets with 100 mm mineral wool is approx. 140 Dkr. without added-value tax. The same cost for postinsulation of the conventional roof (section No. 6) is probably 2 to 3 times as high. The decrease in U-value is 0,07 - 0,12 W/m^2 ^oC. In Denmark we have an average outdoor air temperature in the period of heating of 3^o Celcius giving a number of degree-days of approx. 3000 ^oC days. The indoor air temperature is 20 ^oC.

The energy saving from a decrease in U-value of 0,07 - 0,12 W/m^2 ^oC can be estimated to 4,8 - 8,3 kWh per m^2 per year.

The net price of fuel oil with an efficiency of 75% of the oil burner is 0,39 Dkr./kWh.

This leads to a simple pay back time for the installing of the postinsulation of 43 - 75 years. This pay back period is of course only relevant for the test roof sections, which are very well insulated from the beginning, 0,24 - 0,33 W/m^2 ^oC.

A lower and more attractive pay back time will occur when the roof before postinsulation is less insulated. Postinsulating for instance a 30 mm mineral wool insulated roof with 100 mm freely exposed mineral wool gives a pay back time of approx. 9 years. If the roof is going to be repaired anyway, the economics of the postinsulation will be even more favourable.

CONSLUSION

External postinsulation with weather exposed mineral wool on roofs with a roof pitch of 35^o is a thermal good idea.

Measurements of the U-values for 9 different weather exposed roof sections have shown, that the upside-down roof insulates just as good as the conventional roof with a layer of bitumineous roofing felt on the top of the insulating material. The upside-down roof consisting of outside - 100 mm mineral wool - corrugated steel sheets - not ventilated cavity - 100 mm expanded polystyrene and inside a plastic film insulates just as well as the same roof covered with a roofing felt.

If the same roof is insulated with additional 50 mm expanded polystyrene at the inside we again obtain the same U-value for the upside-down roof and for the conventional roof.

The economics for the postinsulation is favourable, if the roof from the beginning is slightly insulated and also calls for a maintenance of the surface.

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