Moisture in compact roofs -
Results of a two-stage field survey

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SUMMARY:
Compact roof systems that have been well executed, incorporating materials that are not conducive to mould formation between a correctly installed moisture barrier and the roof waterproofing membrane, are not generally considered to be highly susceptible to moisture. Consequently, perhaps insufficient attention has been paid to moisture in compact roofs.
When large amounts of precipitation fell in southern Norway during the autumn of 2000, built-in moisture in compact roofs became an important issue. Relatively large amounts of moisture can become trapped in a roof structure, both in connection with roofing work during periods of heavy precipitation as well as through leakage. This field investigation was carried out in order to study how flat compact roofs perform over time when moisture has been trapped in the construction.
The investigation comprised twelve roofs, ten of which were chosen from roofs we knew had encountered serious problems with built-in moisture during construction (autumn 2000). Two of the roofs did not have any previously known moisture problems and were therefore chosen as reference roofs. Phase 1, which was completed in the summer of 2002, involved the examination of all twelve compact roof constructions. Phase 2, completed in the summer of 2004, comprised an examination of nine of these roofs. The degree of moisture in the roofs was evaluated and information was obtained concerning the type and extent of the moisture problems.
Analysis after Phase 1 showed that moisture levels in seven of the roofs exceeded those found in the reference roofs, and were in excess of what is considered normal. Four of the roofs had moisture levels in the insulation material of 1 % up to 18 % by volume. This implies a reduction of insulation performance of between 3% and 50% at these locations. Microscopic examination revealed evidence of fungal or bacterial growth in seven of the roofs, with substantial growth in two/three of the roofs.
Analysis after Phase 2 showed that moisture levels in four of seven roofs exceeded those found in the reference roofs, and were in excess of what is considered normal. Two of the roofs had moisture levels in the insulation material of 1 % up to 13 % by volume. Microscopic examination revealed evidence of fungal or bacterial growth in all the nine roofs, with substantial growth in two/three of the roofs.
As the measured moisture differences between Phase 1 and Phase 2 were so high, dehydration mechanisms other than diffusion must have contributed substantially to the drying out of the constructions.

1. Introduction

With the high levels of precipitation in Southern Norway during the autumn of 2000, built-in moisture in compact roofs has again become an important issue. Exacting building schedules and heavy precipitation during construction increase the risk of moisture entrapment in the roof structure. Similarly leakages are known to occur during the actual building process, as this is a period often characterised by much movement, traffic and other building activity, even after completion of the roof. In addition, there are many other reasons why roof leakages develop during the building's service life. Sometimes considerable quantities of water can penetrate into a roof.

A "compact roof" is a roof where the various material layers have been laid close together without ventilation. Compact roofs can be executed both as flat roofs (gradient < 6°) and sloping roofs (gradient > 6°) [1]. This is the predominant type of roof construction used for large buildings in Norway. When correctly executed, with non-perishable materials between a correctly dimensioned/ installed moisture barrier [2] and well-executed waterproof roofing, compact roofs are not considered to be highly susceptible to moisture ingress. As a consequence, insufficient attention has been paid to moisture in compact roofs.

The most frequent questions have generally been along the lines: What happens in the long and short term in cases where moisture has been allowed to penetrate the construction? What kind of problems can we expect? Will moisture result in dripping from the roof, corrosion of fastenings, reduced insulating capabilities, rotting of roof woodwork and/or mould formation in the future? Will moisture in the roof construction create problems of such a nature that all moist materials must be replaced, or will there be sufficient natural dehydration through the roofing, parapets, etc. whereby these problems would be avoided?

2. Principal objective and scope

The purpose of the investigation is to establish the extent of moisture in compact roofs, ascertain how roofs with moisture will develop over time, determine whether they will dry out of their own accord or if prolonged moisture creates problems such as condensation droplets, corrosion, reduced insulation capabilities, mould formation or fungal growth. The investigation was intended to give increased knowledge about a roof's dehydrating (self-drying) capability, and the problems we can expect from moisture in compact roofs. This paper presents a few of the results from both Phase 1 and Phase 2 of the field investigation Moisture in compact roofs by concentrating on moisture condition in the roofs, a roof's dehydrating (self-drying) capability and micro-biological growth.

In the next instance, based on existing knowledge and partially on the results provided by this project, guidelines will be developed for use by the roof industry in Norway in order to reduce the degree of building moisture in constructions, and to give recommendations concerning rectification in cases where moisture has penetrated into the roof.

3. The field investigation

3.1 Extent of the field investigation

The field investigation Moisture in compact roofs comprises surveys of twelve compact-roof constructions carried out in two separate stages. Eleven of the twelve roofs are located in Eastern Norway and were examined in June 2002 during Phase 1. The twelfth roof was located in Trondheim and was examined in October 2002. Phase 2 comprises eight of the eleven roofs in Eastern Norway (examined in June 2004) and the roof in Trondheim (examined in October 2004). The Phase 2 investigation was intended to be a follow-up and continuation of the Phase 1 investigation by re-examining a selection of the same roofs after a two-year period.

For reasons of economy the number of roof constructions that were examined were restricted to twelve in Phase 1 and nine of the same twelve roofs in Phase 2. Nevertheless the investigation provides some clear advance indications that can be considered representative for the types of roof construction examined.

3.2 The roofs – localisation and composition

The roofs were chosen so that a majority of the constructions should have encountered actual moisture problems during the build period. On request, a number of key figures in the building trade put forward suggestions regarding buildings where they had experienced moisture problems during construction. As it rained a good deal in the autumn of 2000, causing many problems in Eastern Norway, nine roofs were intentionally picked from among this selection. On roof Nos. 3, 7, 8 and 9 the moisture problems during the build period were reported as being "serious," and on roof Nos. 4, 5, 6, 10 and 11 the moisture problems during the build period were reported as being "very serious." Even though attempts were made to prevent or limit the source of the precipitated moisture by various means, such as covering with tarpaulins, this had only a limited effect. For roof Nos. 4 and 6, ventilation louvres were installed afterwards in an attempt to dry out the building moisture. No other special means of covering, nor subsequent drying-out measures were implemented.

Roof Nos. 1 and 2 had not had any known moisture problems and were therefore chosen to act as reference roofs. When uncovering the reference roofs it was discovered that the moisture barrier over the DT-elements was missing, something that gave an opportunity for some moisture ingress from the inner side for most of the year (and drying-out inside the building during other parts of the year).

Finally a portion of the roof above an office wing at NSB's premises in Trondheim was examined. This proved to be of great interest because five years previously this particular roof had been executed as an experimental roof and had been pre-fitted with instruments enabling measurements to be taken of moisture/ humidity and temperature after a given amount of water (1 litre per m²) had been applied to the roof construction. [3] Table 2.1. indicates the roofs covered by the investigation.

TABLE 1:Examined roofs, with indications of presumed extent of building moisture and composition of the roof structure

Roof No.	Useage Area (m²)	Roofing year	Presumed extent of building moisture	Composition of roof structure	Examined in Phase
1	Warehouse 2400 m²	2000/ 2001	Normal	Single-layer bitumen roofing, 50 mm mineral wool insulation, DT-concrete elements w/ open joints (no moisture barrier)	1 & 2
2	Warehouse 800 m²	1989	Normal	Dual-layer bitumen roofing, 50 + 30 mm mineral wool, DT-concrete elements w/ open joints (no moisture barrier)	1 & 2
3	Office block 750 m²	Autumn 2000	Serious	Dual-layer bitumen roofing, 50 mm mineral wool, + 200 mm EPS, PE-foil moisture barrier, concrete.	1
4	Office wing 1200 m²	2000/ 2001	Serious	Bitumen roofing, 200 - 300 mm mineral wool, PE-foil moisture barrier, steel supporting plates.	1 & 2
5	Offices 500 m²	2000/ 2001	Very serious	PVC roofing foil, 100 mm mineral wool, PE-foil moisture barrier, 50 mm mineral wool, steel supporting plates	1 & 2
6	Packing house 3000 m²	2000/ 2001	Very serious	Bitumen roofing, 100 mm mineral wool, PE-foil moisture barrier, 50 mm mineral wool, perforated steel supporting plates.	1 & 2
7	Office wing 150 m²	Autumn 2000	Serious	Single-layer bitumen roofing, 50 mm EPS insulation, wooden under-roof (no moisture barrier)	1
8	Material store 900 m²	Autumn 2000	Serious	Dual-layer bitumen roofing, 200 mm mineral wool, bituminous moisture barrier w/loose overlaps, steel supporting plates.	1
9	Residential and day-care centre 450 m²	2000/ 2001	Serious	PVC roofing foil, matted glass-fibre migration barrier, 200-250 mm EPS, PE-foil moisture barrier, concrete.	1 & 2
10	Sports hall 800 m²	Autumn 2000	Very serious	PVC roofing foil, 200-250 mm mineral wool, PE-foil moisture barrier, concrete.	1 & 2
11	Shopping mall 5000 m²	2000/ 2001	Very serious	PVC roofing foil, 200-250 mm mineral wool, old roofing foil, 150 mm old mineral wool PE-foil moisture barrier, steel supporting plates.	1 & 2
12	Office wing 600 m²	1997	Serious	FPO roofing foil, 30 mm mineral wool, + 0-100 mm EPS, old PVC roofing foil, 50 mm old insulation, Dina elements filled with insulation.	1 & 2

3.3 Field investigation – observations and measurements

A survey report was made for each of the roofs giving details of the participants, building, roof geometry and design/construction, as well as date of the roofing work. The actual examinations were made by taking measurements and observations at three to five points along an imaginary line drawn across the roof. The constructions were uncovered in order to make more detailed observations, take measurements of moisture content such as RH/temperature measurements, as well as take samples of roof insulation materials for more accurate evaluation back in our own laboratory. In addition, during Phase 1, holes were made in the roofing at other points for the measuring-gauge probe so that temperature/RH readings could be taken. This measurement method proved to be so ineffective it was discontinued in Phase 2 and more emphasis was placed on uncovering, observing and sample taking. The measurement and observation points in Phase 2 were positioned adjacent to those chosen in Phase 1 and simply moved approx. 0.5 m so that new samples could be taken from an undisturbed area.

The survey reports contain pictures and sketches showing the measuring point locations as well as detailed observations and measurements.

Sample taking and analyses with a view to possible microbiological growth formed an important part of the investigation. Mycoteam AS and SINTEF Energiforskning A/S assisted us with these examinations. The salient points from the Mycoteam [4], [5] and SINTEF [6], [7] reports are included in this paper.

FIG. 1: Roof No. 11. A building from 1980 that was re-roofed late autumn 2000. Pictures taken during survey in Phase 1 June 2002.

3.4 Concerning moulds/fungi and investigation of micro-biological activity

In this paper we have differentiated between moulds, blue-stain fungus, wood-decaying fungus, yeasts and bacteria. Dispersal of the fungi species mentioned is by means of microscopic spores which are spread by air currents and which are found in the air everywhere. Both viable and dead spores are to be found. It is difficult to give simple general rules for the criteria that determine growth. Access to nutrients, moisture, oxygen, temperature and time are important factors affecting growth. For mould RH ≥ 80 % and t ≥ 0 °C is a normal, but simplified criterion for growth on surfaces.

In connection with the investigation into fungal growth and other possible biological activity, material samples were taken of roofing, insulation and moisture barriers. In addition, samples of outside air and of air from within the roof construction were collected for cultivation in the laboratory.

4. Some results from the investigation

4.1 Moisture content of insulation samples

Table 2 shows the results of the laboratory investigation of moisture content in samples of insulation materials from the roofs. For practical reasons samples were not taken from roof Nos. 7 and 8 during Phase 1 and were therefore not included in Phase 2. Roof No. 3 had been modified in the meantime and was consequently no longer of interest.

TABLE 2: Comparison of measured moisture content in insulation samples taken from roofs Nos. 1 to 12 in Phases 1 and 2. NB: A moisture content of 1 % (volume) in 100 mm thick insulation yields 1 litre of water per m².

Roof No.	Useage	Sample point	Type of insulation	Phase 1 - Summer 2002		Phase 2 - Summer 2004	
				%-weight	%-volume	%-weight	%-volume
1	Warehouse	P1-U	Mineral wool	0,41	0,07	0,29	0,05
		P2-U	“	0,41	0,07	0,28	0,04
		P3-U	“	0,43	0,07	0,29	0,05
		P4-U	”	-	-	0,25	0,04
2	Warehouse	P1-U	Mineral wool	0,31	0,03	0,22	0,03
		P1-L	“	0,34	0,07	0,12	0,01
		P5-U	”	-	-	0,15	0,03
		P5-L	”	-	-	0,55	0,06
3	Office building	P2a-U	EPS	0,75	0,02	-	-
		P2b-L	Mineral wool	0,38	0,06	-	-
4	Office wing	P1-U	Mineral wool			0,38	0,08
		P1-L	”			0,22	0,03
		P2-U	”			0,31	0,06
		P2-L	”			0,40	0,05
		P3-U	”	3,31	0,40	0,24	0,03
		P3-L	”			0,36	0,03
5	Office/lab/	P1-U	Mineral wool	150,0	17,8	93,7	13,13
	workshop	P1-OMB	“	225,0	17,6	-	-
		P1-UMB	“	0,6	0,07	0,31	0,04
		P2-U	”			0,47	0,08
		P2-OMB	”			-	-
		P2-UMB	”			0,28	0,03
6	Packing house	P1-OMB	Mineral wool	11,0	1,0	0,42	0,06
		P1-UMB	”			0,22	0,03
9	Residential and	P1-U	EPS	0,87	0,02	0,72	0,01
	day-care centre	P1-L	EPS			0,44	0,01
		P2-U	EPS	34,0	0,55	0,70	0,17
		P2-L	EPS			0,09	0,06
		P3-U	Mineral wool			0,37	0,01
		P3-L	Mineral wool			0,97	0,01
		P3-L’	EPS			0,60	0,00
10	Sports hall	P1-ØU	Mineral wool	0,33	0,05	0,33	0,06
		P1-L	Mineral wool			0,25	0,02
		P2-U	EPS			0,79	0,02
		P2-L	EPS			0,48	0,01
		P3-U	Mineral wool	0,36	0,06	0,36	0,04
		P3-NL	Mineral wool			0,40	0,04
11	Shopping mall	P1-U	Mineral wool			0,24	0,04
		P1-UOR	“	0,41	0,06		
		P2-U	“			0,37	0,06
		P2-UOR	”	14,32	1,2	13,1	1,29
		P3-U	”			1,7	0,23
		P3-UOR	„	1,4	0,2	38,8	5,52
		P3-L	”			13,4	1,42
12	Office wing	P1-upper	Mineral wool	0,34	0,03	0,31	0,06
		P1-centre	“	0,41	0,07	-	-
		P1-lower	”	0,37	0,08	0,33	0,04
		P6-upper	Mineral wool	0,62	0,14	0,33	0,06
		P6-centre	EPS	1,18	0,02	-	-
		P6-lower	EPS	1,65	0,03	1,88	0,03
		P7-upper	Mineral wool	1,35	0,21	0,55	0,10
		P7-lower	EPS	1,66	0,03	2,18	0,04
		P9-upper	Mineral wool	7,93	1,43	0,5	0,09
		P9-UGT	EPS	-	-		

Key to abbreviations used in third column:
P1, P2, P3, P1a etc. refer to sampling points on each of the roofs
U = Uppermost portion of the insulation layer
L = Lowermost portion of the insulation layer
OMB = Insulation immediately over moisture barrier where there is an insulation layer between supporting structure and moisture barrier
UMB = Insulation immediately under moisture barrier where there is an insulation layer between supporting structure and moisture barrier
UOR = Underneath old roofing

4.2 Some results from the investigation into micro-biological activity

In Phase 1 viable spores of mould and/or bacteria were found in ten of the twelve roofs examined. On the roofs where no spores were discovered (roof Nos. 4 and 8) samples were only taken at one place. Examination by microscope revealed growth of mould and/or bacteria in six of the roofs. Only in two/three of the roofs were substantial discoveries made.
In Phase 2 viable spores of mould and/or bacteria were found in all nine roofs. Examination by microscope revealed mould and/or bacterial growth in all nine of the roofs.
In the period between Phase 1 and Phase 2 probable growth of fungus and bacteria was registered in seven of nine roofs (sparse growth in five, moderate growth in two). Two of these roofs had the combination of substantial moisture/ moderate to substantial microbiological activity when examined in Phase 1 and moderate growth in the period between Phase 1 and Phase 2:

- Roof No. 11 had a high concentration of bacteria and yeasts in one of the test holes in Phase 1. The amount of fungal spores was greater in 2004 than in 2002, something that indicates growth during the period. Considering the construction had been standing wet for several years, the level of biological activity was however relatively low.
- Roof No. 12 had proven moderate to substantial growth of two kinds of moulds, and is probably already suffering from established fungal damage.

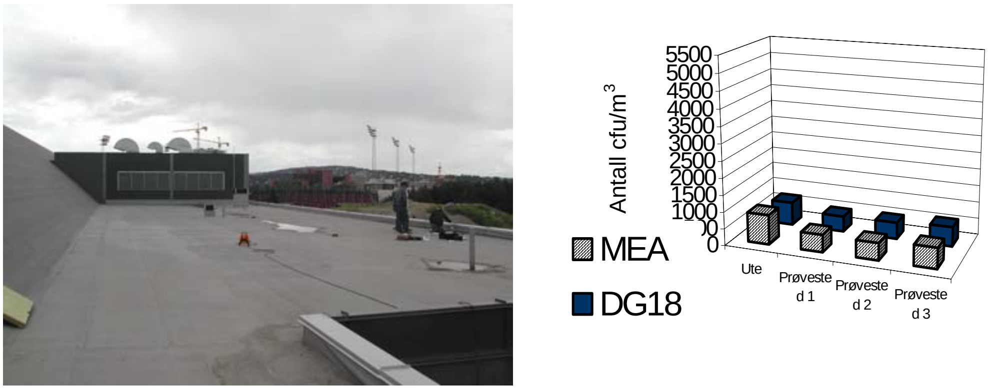

Fig. 2: Example Roof No.10. Overview as well as graphic reproduction of results from the air analyses. Number of cfu/m³ is shared between sampling point and cultivation medium (MEA/DG/18) (Phase 1)

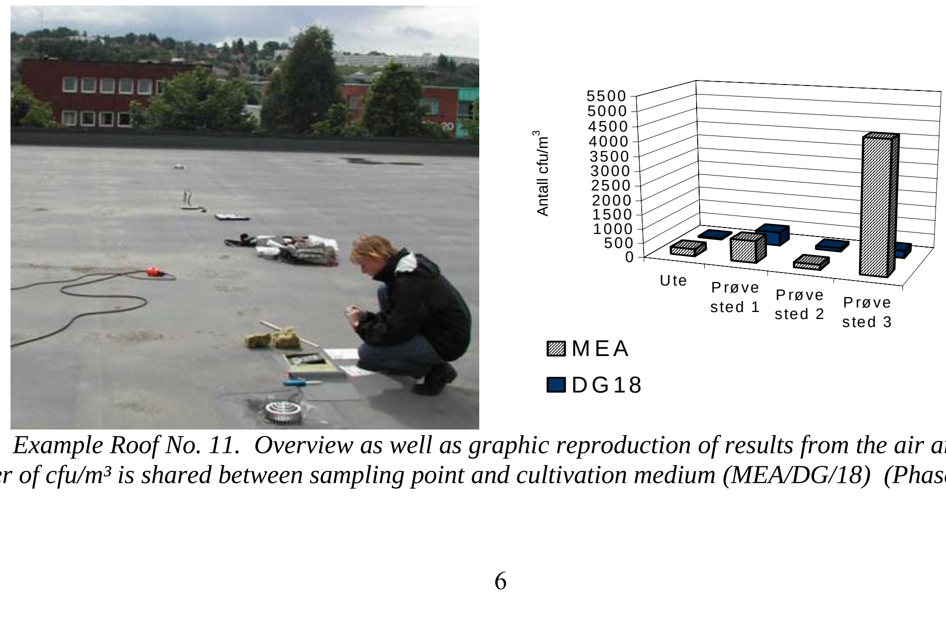

Fig. 3: Example Roof No. 11. Overview as well as graphic reproduction of results from the air analyses. Number of cfu/m³ is shared between sampling point and cultivation medium (MEA/DG/18) (Phase 1)

TABLE 2: Summary of analysis results in 2002 and 2004.

Roof No.	Registeredgrowth in 2002 (Phase 1)	Registeredgrowth in 2004 (Phase 2)	Presumed growth from 2002 to 2004	Comments
1	Yes (very sparse)	Yes (very sparse)	No	Relatively little growth ☺
2	No	Yes (sparse)	Yes (sparse)	Relatively little growth ☺
3				Not examined 2004
4	No	Yes (sparse)	Yes (sparse)	Relatively little growth ☺
5	Yes	Yes	No	About average with regard to amount 😐
6	Yes	Yes	Yes (sparse)	Relatively little growth ☺
7				Not examined 2004
8				Not examined 2004
9	Yes	Yes	Yes	One of the roofs with highest micro-biological activity 😐
10	Yes	Yes	Yes (sparse)	Relatively little growth ☺
11	Yes	Yes	Yes	One of the roofs with highest micro-biological activity 😐
12	Yes	Yes	Yes	One of the roofs with highest micro-biological activity 😐

5. Discussion

Reports received from the roof entrepreneurs at the beginning (concerning the building-in of considerable amounts of moisture from precipitation into the roofs) seem to be confirmed by Phase1 of the investigation. Nevertheless, in several places we could see that even though moisture had quite clearly penetrated into the roofs, there was less evidence of moisture in the roofs 1½ years after the roofing period than the reports from the roofing period would suggest. In Phase 2, after a further two years, this impression was reinforced.

There are several mechanisms contributing towards drying out of possible moisture in compact roofs over a period of time: outward diffusion through the roofing, inward diffusion, convection currents in the roof and outward diffusion via the parapet, as well as lesser incidental air currents through all or portions of the roof surface.

Drying out (dehydration) via outward diffusion through the roofing is minimal and varies according to the type of roofing and also eg. with the outside temperature. In the field investigation "Moisture in compact roofs" eleven of twelve roofs were located in the southeastern part of the country. Table 3 shows the extent of dehydration by means of outwards diffusion through the roofing under typical Eastern Norway climatic conditions and with single-layer PVC roofing or bituminous roof covering.

Table 3 Extent of drying out (dehydration) by means of outward diffusion through the roofing

Water-vapour permeance – Roofing	PVC roofing foil	Bituminous roof covering
Typical resistance to water-vapour permeance	Zp = 75 . 109 m^2 . s . Pa/kg or Sd = 15 m	Zp = 515 . 109 m^2 . s . Pa/kg or Sd = 100 m
Typical self-drying potential: summer Typical self drying potential: winter Typical self-drying potential: per annum	ca. 20 g/m^2 . month ca. 5 g/m^2 . month ca. 120 g/m^2 . year	ca. 5 g/m^2 . month ca. 0 g/m^2 . month ca. 20 g/m^2 . year

Compared to what was assumed beforehand, measurements in several of the roofs showed that dehydration was so extensive that mechanisms other than pure diffusion had possibly been a dominant factor in several instances.

Use of ventilation louvres. In order to assist with the drying out of building moisture, ventilation louvres were installed on two of the roofs (Roof Nos. 4 and 6) after the building was completed but prior to the examinations in Phase 1. The sizes, quantity and locations were different on the two roofs. When we returned to implement Phase 2 we could see that the ventilation louvres had been removed from both roofs. We were told that this was because the roofs in the meantime were considered to be dry and that ventilation louvres were therefore no longer necessary. As an example we would mention roof No. 6: A large number (64) of ventilation louvres were retrofitted in the bituminous roof covering (see fig 4). The moisture content of the mineral wool in Phase 1 was measured as being 1.0 % (volume). This is a fairly high moisture content. The position of the sampling point was approx. 2 m away from four of the ventilation louvres. As we do not know how much moisture was present in the roof from the start, it is difficult to judge the effect of the ventilation louvres up to the examination in Phase 1. The drying out that was registered between Phase 1 and Phase 2 (measured value in Phase 2 was 0.06 % by volume) is however so large that dehydration mechanisms other than pure diffusion must have had a significant effect. It therefore looks as if the ventilation louvres have made a positive contribution.

Fig 4. Overview of roof No. 6 in the investigation and details of ventilation louvre (photo: NBI)

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