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# ROOFS AND ROOFING IN SWEDEN

Lars Nevander
Professor of Building Technology, Lund University, Lund, Sweden

At Lund University's building technology department we have made fundamental research on heat and moisture transfer in building structures and applied this knowledge to different building components, especially to roofs. We found that the basic knowledge of roofing was limited, and it was natural to study these problems further. Our scope has been expanded also to steep roofs, e.g. with tiles.

First, however, it might be worthwhile to give a very short description of roofs and roofings commonly used in Sweden.

## Types of roofs

Roofs can be either steep or flat.

Steep roofs predominate among single family homes. Concrete tiles are generally used and have largely replaced clay tiles. Asbestos-cement roofs were used earlier but are nowadays forbidden due to cancer risk when handling asbestos. Roofing felt and metal sheet - plain or corrugated - are also used, shingles only to a small extent. Covered area is estimated at 6.5 million square meters per year.

Flat roofs on industrial and commercial buildings, schools, etc. are covered with membrane roofs. Terraces are of the same type. Covered area is estimated to be 8 million squre meters per year, including 0.4 million square meters re-roofing.

Only flat roofs of the last mentioned type will be dealt with in this paper.

## Roofing membranes

In flat roofs, bituminous roofing is used on nearly 90% of the covered area. The use of one-ply systems is estimated at the following:

| | |
|---|---|
| Butyl rubber IIR | 5% |
| Polyvinylchloride PVC | 2% |
| Polyisobutylene PIB | 1% |
| Others | 3% |

One-ply systems do not differ much from what is used in other countries of Europe or in the USA. The bituminous roofing systems, however, are quite different from those used in the United States.

All roofing felts are saturated and coated with asphalt. Coal tar is not used in Sweden. Glass fibre has almost replaced the rag felt. Felt with high wood-fibre content is not used. The following types are the most popular:

- YAM - Coated saturated glass fiber felt, 50 $g/m^2$ with totally 1200 $g/m^2$ of asphalt, used as non-exposed plies in general.
- YAL - Same, but with a rag felt of 325 $g/m^2$.
- SAM - Mineral-surfaced, coated, saturated glass fiber felt 60 $g/m^2$ with totally 1600 $g/m^2$ of asphalt, used as an exposed outer ply on a roofing.
- SAL - Same, but with a rag felt of 600 $g/m^2$ and an asphalt content of 1800 $g/m^2$.
- KoAM - A YAM felt covered on the underside with grains of polystyrene beads and generally spot-mopped in order to get a pressure releasing layer.
- YAGv - A 3 or 5 mm asphalt mat with glass fiber fabrics, generally 90 $g/m^2$. Asphalt content 2700 or 4500 $g/m^2$ respectively. The asphalt mat also exists with a hessian base.

The bituminous roofing systems are generally two or three-ply systems. Two plies are used at slopes of more than 1:4. For horizontal roofs - slope less than 1:40 - the middle ply in the three-ply system generally consists of an asphalt mat.

On air tight substrates the first ply is generally grain-covered KoAM.

The upper layer is most often a mineral-surfaced felt but sometimes the roofing is covered with gravel.

Fig. 1 shows the felt pattern of a typical builtup roof membrane.

## Thermal insulation

Buildings in Sweden have generally been well insulated. The energy crisis and the increase in fuel costs have increased the insulation level further. A new building code went into effect on July 1, 1977, and the requirements on thermal insulation of roofs are quoted in Table 1.

The larger thicknesses will certainly create some new problems.

The influence of cold bridges will be larger in relative measures and cannot be overlooked in design. Also the influence of imperfections will be larger. Experience indicates that air movements in air spaces and openings can be very detrimental to the thermal insulation. In general, one can say that it is easy to prescribe these thick insulations, but it is very difficult to make them perform according to their theoretical potential.

Many materials will have to be applied in two layers, which may require mechanical fastening. The alternative will perhaps be a loose-laid system with gravel on the roofing.

The larger thickness will make the roofing substrate more deformable and can cause problems at flashings, especially at vertical upstands but also at built-in gutters and at the mechancial fasteners.

There may be a tendency to develop new types of sandwich-boards, where the upper layer gives a satisfactory rigidity and the lower layer gives the thermal insulation in the cheapest way.

## Moisture design

Calculations of non-stationary moisture transfer have been made (1) for a number of solid flat roofs of concrete or cellular concrete with or without additional thermal insulation, Fig. 2 and 3.

Some important results from the calculations may be observed:

Thermal conditions in the roof have a great effect on moisture contents, and therefore the boundary conditions have been treated very thoroughly. Air temperature, solar radiation, absorption properties and cloudiness must be considered in the calculations.

In solid roofs it is seldom necessary to take the diurnal or even the annual variations in the climate into consideration. Calculations based on annual mean values of the boundary conditions are surprisingly accurate, and this is due to the fairly high moisture capacity in these roofs which will decrease the oscillations.

For roofs with high moisture capacity it is misleading to base the judgement of vapor barriers on static conditions in the cold season.

The initial moisture content must be considered.

When there are joints, holes or cracks in the roof, the moisture transfer with streaming air – which we call moisture convection – has to be considered.

The moisture transfer in roofs of profiled steel decks with thermal insulation on top and a roofing has been investigated (2). The investigation shows moisture transfer into the heat insulation and condensation when there is no vapor barrier. The moisture passes through holes and joints in the steel deck mainly because of air pressure gradients – moisture convection.

Even though the steel deck itself does not act like a vapor barrier there is in most cases no need for a special vapor barrier. Condensed water in these small amounts does not cause damages, just a slight decrease in thermal performance, and will generally dry out when the sun is shining on the roof, Fig. 4. There will be more water condensed in open materials like rockwool and glass fiber than in tight materials like polystyrene foam plastics and accordingly differences in the decrease of heat insulation.

Water will not drip from such temporary condensation within the materials. In open joints between the insulation slabs, however, larger amounts of water may condense under the roofing felt and even freeze into ice. At a rapid increase of the roofing temperature the melting ice may drip down into the flutes and even through the steel deck and cause damages. In this case rockwool or glass fiber are better than the non-absorbing polystyrene foam plastics.

Under special conditions, i.e. very humid interior, or indoor overpressure, moisture content in the roof will reach an unacceptable level. In these cases, the roof must have a vapor barrier on top of the steel deck and below the heat insulation.

Vapor barriers always involve certain risks. Rain leakage, or precipitation during construction will remain inside the heat insulation and can cause more damage than small amounts of condensed water (3).

When a vapor barrier is necessary, it is often more important that it stop moisture convection than moisture diffusion. Generally, we favor the modern concept: "If in doubt, omit the vapor barrier".

# PERFORMANCE OF ROOFING SYSTEMS

In this paper no attempt will be made to make a complete and logical performance analysis, but I will try to point out where we have difficulties at present and where we might have some interesting experiences or test results to report.

A report on our own tests has been published (4).

### Draining of water

Generally the concept of warm and cold roofs is used for designing the drainage system. Cold roofs should have such good ventilation of an attic or an air space that the roofing gets almost the same temperature as ambient, which makes it possible to use exterior perimeter drainage. In warm roofs there is always heat flow through the roofing, which can melt snow. The melted water must be drained off by interior gutters or it will freeze again when it reaches the cold perimeter. Sometimes, however, it is difficult to foresee if a roof will perform as a cold roof and consequently, ice dams can be created.

The winter in northern Sweden 1974/75 had unusually heavy snow and intermediate periods of thawing. Experiences from this winter have been gathered and will be published.

Ordinary gutters to interior draining tubes have proved to remain open during the whole winter. Evidently warm air is rising from the sewage system, which melts the snow at the gutters. Exterior gutters and over-flow drainings are generally frozen and cannot be expected to perform in winter.

However, the problem has been that melting water does not drain under the snow cover. It seems that after some time the bottom part of the snow cover is so dense that it is impervious to water. The result has been that there have been severe pondings around ventilators, where local melting easily occurs. Sometimes the water level has risen above the upstands of the roofing and it is then quite natural that leakage has occurred, Fig. 5.

The real problem is how to improve the drainage under a snow cover. We hope that a gravel covered surface may perform better, but there does not yet exist any systematic studies of its performance.

### Wind blow off

Another important performance attribute is that the roofing shall remain in place and not blow off in hard wind.

Our failures are mainly related to two types of roofs.

On wooden substrates the first ply is generally nailed to the wooden panel. The nail holding power has been tested and some results are given in Fig. 6 and 7.

According to the test, nail pullout strength is somewhat larger than the nail head pull strength. It might, however, be mentioned that nail head diameters are rather small in Sweden, 9-12 mm. The tests have very little correlation to the standard tests for mechanical strength of a roofing felt, which means that this does not give any guidance to the performance of the roofing felt with regard to wind uplift.

Formerly it was usual to nail the first ply with 27 nails per $m^2$. The design wind uplift load on local parts of the roof according to the present Swedish building codes is of the magnitude of 3.5kPa[1] for a 15 m high building. This means 130 N[2] per nail, and comparing with Fig. 3 it is rather natural that we have had a number of blow-offs.

The standard specifications has after this investigation been changed to 54 nails per $m^2$ on the most exposed parts of the roof.

Wind blow-off has also been too frequent on metal decks with thermal insulation. In order to get a good bond between the corrugated sheet and the insulation it has proved to be necessary to apply asphalt both on the deck and on the insulation. In the beginning the glass fiber and rockwool batts had a tendency to delaminate, but this has to a large extent been overcome. The system with asphalt mopping is, however, very sensitive to workmanship and the safety factor is considered to be very low. Therefore we nowadays use more and more mechanical fastening. The increasing thickness of the insulation also contributes to this tendency.

### Splitting

Splitting may result from tension in the membrane itself, from movements in the substrate or from movements in an ice layer on the membrane.

We have no evidence that thermal expansion or contraction of the membrane itself has caused damages, nor that moisture movements have had such effects. Some experimental one-ply systems have had an intrinsic shrinkage which caused leakages at the flashings, but they are not used any more.

Movements in the substrate, however, are always a great problem. In Sweden, we have often used cellular concrete slabs on industrial buildings. In the beginning we had very large problems with splitting, especially over the supports. Some 10 years ago the spot-mopped, grain-covered roofing felt was introduced mainly in order to avoid blistering. At the same time the splits almost disappeared. The explanation was of course that the tension length was increased so that the stress in the roofing membrane was considerably lower.

Today's problem is splitting in membranes on polystyrene foam plastics. Mainly two different techniques are

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[1] kPa = kilopascal. 1 kPa = 1 kN/$m^2$ ≈ 21 lbf./sq. ft.
[2] N = Newton. 1 N ≈ 0.22 lbf.

used. The first layer may be a grain covered roofing felt which is spot mopped on its backside and then laid down on the foam plastic. The foam plastic is susceptible to heat and this technique is sometimes troublesome. Therefore it has been common to apply the first layer of an ordinary roofing felt at the factory and then the roofing can be made in an ordinary way at the building site.

Splitting has occurred over the joints of the polystyrene boards and movement of the whole insulating layer towards the center of the roof has caused leakage at the perimeter.

It is generally considered that thermal movements of the insulation boards more or less in combination with shrinkage are causing these damages. These problems are now being studied in both Norway and Sweden.

It might seem somewhat contradictory that the experiences are good with grain covered roofing felt on cellular concrete slabs but not so good on foam plastics. The joint movements in the cellular concrete deck are certainly large, but they occur mainly only once. The thermal response of such a deck is slow and the repeated movements are small. On a foam plastic insulation the roofing – without gravel coating – and the upper side of the insulation will be exposed to much larger temperature differences and much more often. There will be a considerable fatigue effect. This is also in some way confirmed by the practical experiences that the damages occur after some years.

If the pathology of the damage is unknown, it is difficult to combat it. The trend in Sweden seems to be either to use some kind of sandwich insulation board or to use roofing felt with a much larger elongation at rupture, say 20%. These roofing felts have a base of polyester mat and contain special rubber asphalt. Loose-laid systems can also be used but they must be covered by gravel.

Splitting due to an ice layer on the roofing is a serious matter, because there is no simple remedy against it. The phenomenon is generally explained in the following way. If the ice is frozen just below the freezing point and then cooled to a lower temperature, it will contract like any other material. On large areas the tensile strength of the ice may be exceeded and the ice splits. The ice may be so well bonded to the roofing that the roofing also splits. Calculating with normal tensile strengths of roofings and ice one can show that the thickness of the ice layer does not have to be more than a few centimeters in order to cause cracking of a normal roof. It seems impossible to prevent splitting by increasing the strength of the roofing membrane, but increasing the elongation at rupture might be a possible solution. Decreasing the bond between ice and roofing membrane could be another solution but will certainly influence the fire resistance. It is possible that a gravel coated roofing behaves better.

Even if these damages hitherto are very few and not certainly confirmed, the interesting point is why they have started just now. Roofing with the same mineral surfacing has been used for a long time in Sweden. Is it the thicker insulation that keeps the roofing colder, or is it the smaller slopes, or is it the glass fiber base in the roofing felt which decreases the deformation capacity that has created the problems? Can we expect an increasing number of such failures in the future?

**Blisters**

The frequency of blistering has decreased dramatically since we have changed into the glass fiber roofing felts and used grain coated membranes as a first layer on all substrates impermeable to air. Of course some interply blisters still occur.

**Puncturing**

Puncturing is not a large problem but it is desirable to have some means of evaluating the resistance to puncturing, especially for thin one-ply systems. In the laboratory we have tried to simulate puncturing with four different testing methods according to Fig. 8.

The thicker bituminous membranes are generally more resistant to such mechanical action than thinner one-ply systems of rubber or plastics. The detrimental effect is, however, very much dependent on the substrate. Membranes of rubber or plastics are in general more resistant to such mechanical action when laid on a very hard substrate like steel or on a very soft one like glass fiber or rockwool than on substrate of intermediate softness like wood.

It will be very difficult to state some performance level corresponding to actual exposure as the conditions in practice can vary within broad limits.

**Practical Experiences**

Roofing contractors generally give a 10 or 15-year guarantee on the durability of the roofing membrane and more or less on the performance of the roofing system.

"Small" failures, like slippage, leakage at flashings, blisters, wrinklings, disjoining, etc., which are often due to bad design or poor workmanship, have decreased during recent years, whereas "large" failures like wind blow-offs, ice-splittings, and splittings on foam plastics have increased.

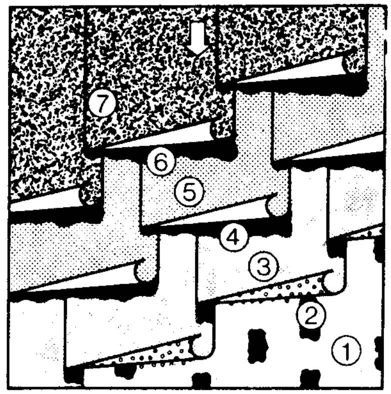
It is difficult to judge whether roofing technology is good or bad in Sweden. The cost for repairing failures, which are covered by the guarantee, can be estimated to be 0.5-1% of the total contracting sum. As mentioned in the beginning, re-roofing is about 6% of the total roofing. These two figures may indicate that the quality of the roofing in Sweden is rather good.

## REFERENCES

1. Sandberg, P.I.: *"Moisture Balance In Building Elements Exposed to Natural Climatic Conditions."* Lund Institute of Technology, Division of Building Technology, Report 43, 1973. In Swedish[1] with an English summary.
2. Samuelson, I.: *"Moisture Transfer In Steel Deck."* Lund Institute of Technology, Division of Building Technology, Report 67, 1976. In Swedish[1] with an English summary.
3. Vos, B. H. & Tammes, E.: *"The Hygric Aspects of Solid Stony Flat Roofs."* 2nd International CIB/TILEM Symposium on Moisture Problems in Buildings, Rotterdam 1974.
4. Sandberg, P. I.: *"Roofing Membranes, Part I."* Lund Institute of Technology, Division of Building Technology, Report 79, 1976. In Swedish with an English Summary.

[1] Contributions from this report have appeared in English at the Symposium in Rotterdam 1974, see ref. no. 3.

FIGURE 1 - TYPICAL ROOFING ON A NONPERMEABLE SUBSTRATE WITH SLOPE > 1.5°. 1. SUBSTRATE, 2. SPOTMOPPING, 3. GRAIN-COVERED ROOFING FELT KoAM, 4. FULL MOPPING 1 kg/m$^2$ (20 lbs/sq), 5. COATED ROOFING FELT YAM, 6. FULL MOPPING, 7. MINERAL-SURFACED COATED ROOFING FELT SAM or SAL.



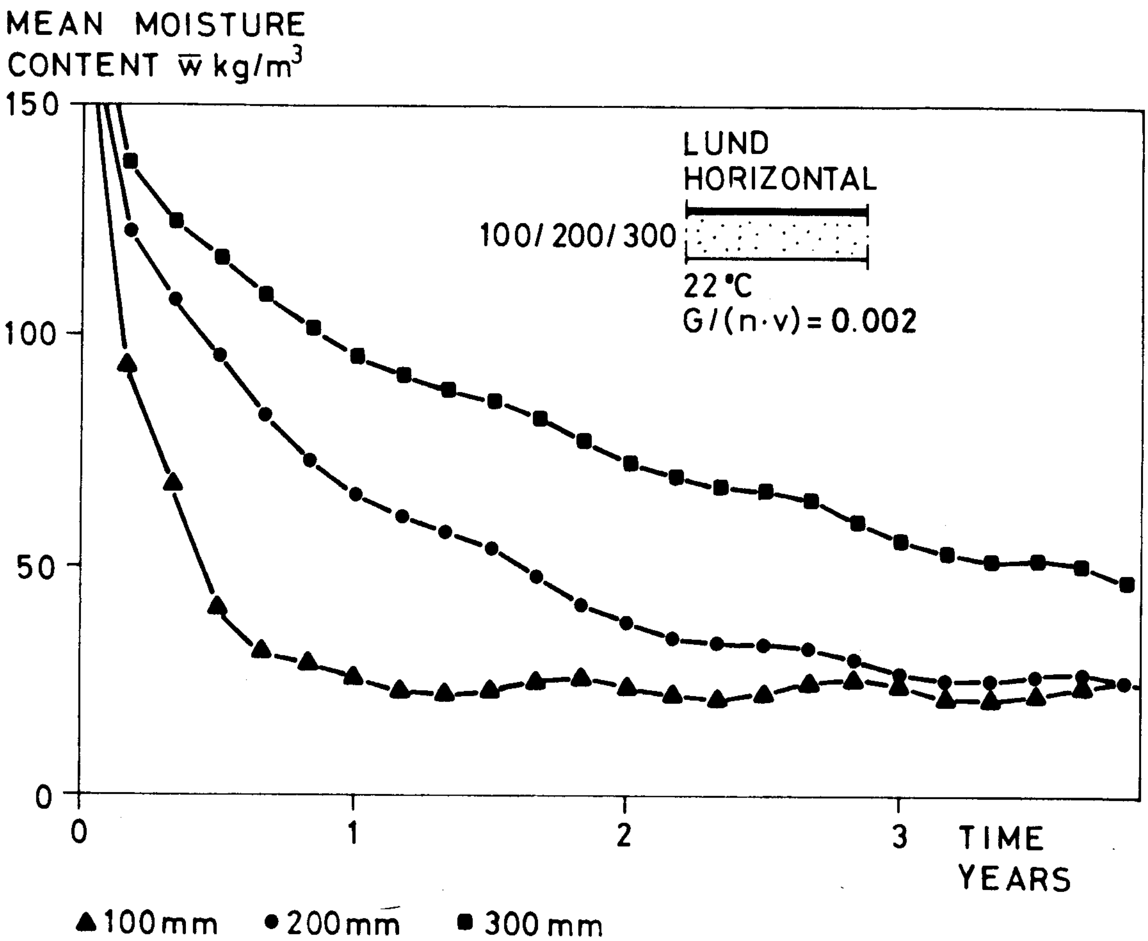




FIGURE 2 - HYGRIC PERFORMANCE OF CELLULAR CONCRETE ROOFS OF DIFFERENT DIMENSIONS. NOTE THE SMALL ANNUAL VARIATIONS IN THE MEAN MOISTURE CONTENT. G/n·V = 0.002 MEANS THAT THE SPACE BELOW THE ROOF HAS A CONSTANT MOISTURE PRODUCTION AND VENTILATION RATE SO THAT THE DIFFERENCE BETWEEN MOISTURE CONCENTRATION IN THE AIR INSIDE AND OUTSIDE IS 0.002 kg/m$^3$.

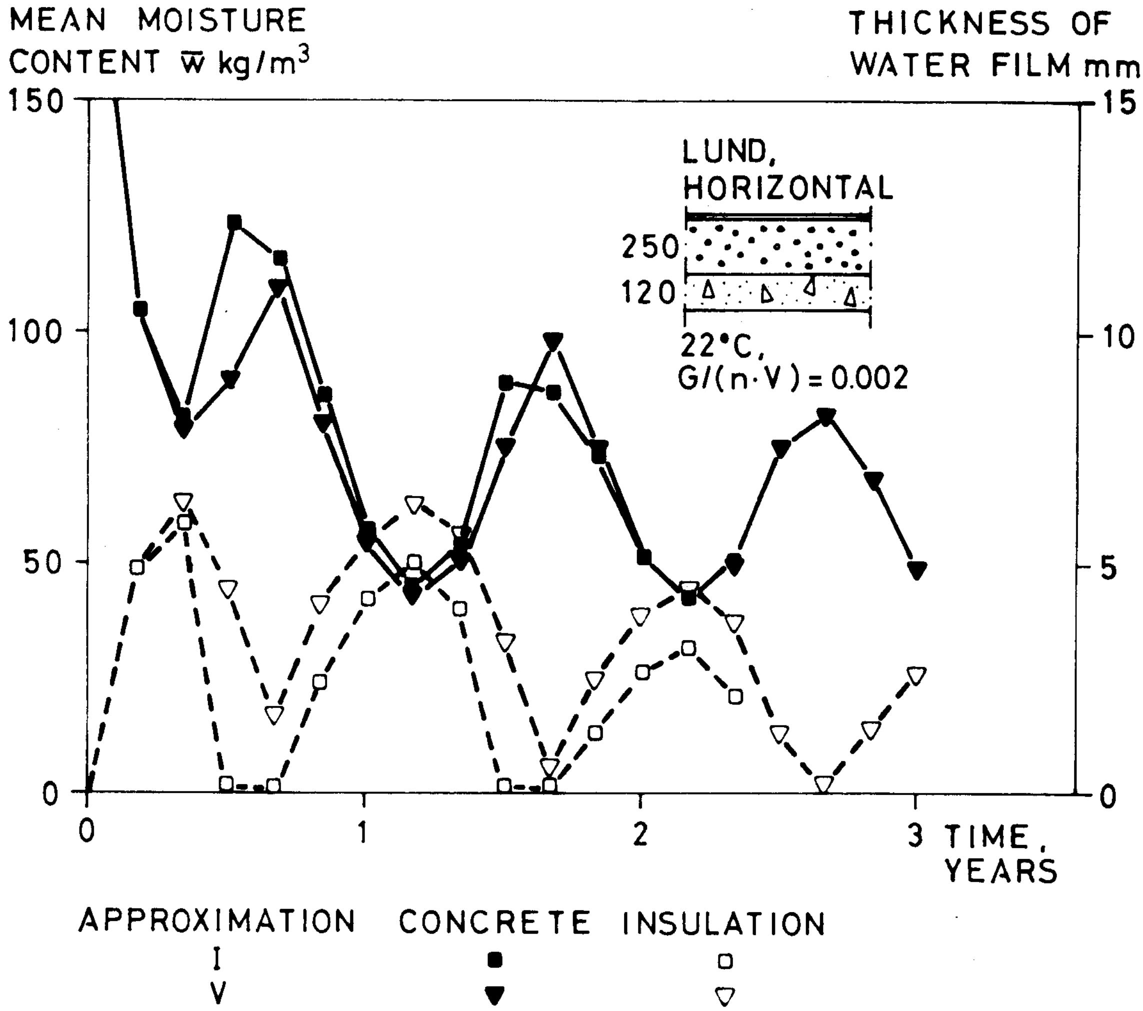



FIGURE 3 - MOISTURE CONTENT IN A CONCRETE ROOF INSULATED WITH EXPANDED CLAY (LECA). LEFT AXIS REFERS TO THE MOISTURE CONTENT IN THE CONCRETE AND RIGHT AXIS TO THE MOISTURE CONTENT IN THE INSULATION WHICH IS ASSUMED TO BE CONCENTRATED TO A THIN LAYER JUST BELOW THE ROOFING. IN APPROXIMATION I THE TEMPERATURE FIELD IS TREATED VERY ACCURATELY AND IN APPROXIMATION V ALL DIURNAL VARIATIONS IN THE BOUNDARY HAVE BEEN REPLACED BY MEAN VALUES.

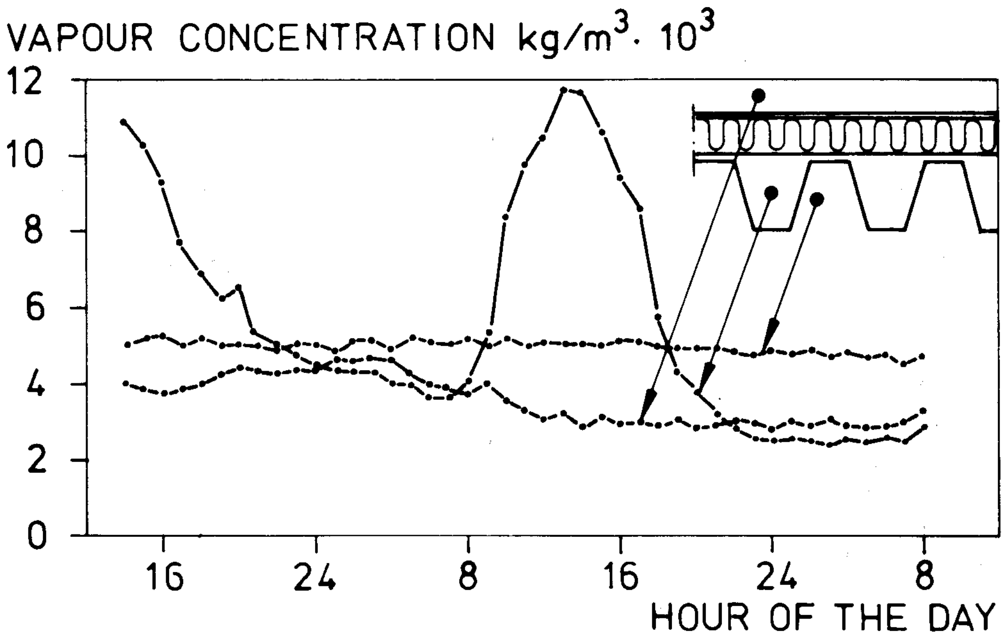



FIGURE 4 - THE VARIATIONS OF THE VAPOUR CONCENTRATION IN A ROOF OVER A STOCKROOM FOR VEGETABLES AND FRUITS. NOTE THE INCREASE IN VAPOUR CONCENTRATION IN THE DUCT IN DAYTIME, DEPENDING ON SUNSHINE AND EVAPORATION FROM THE INSULATION SLABS.

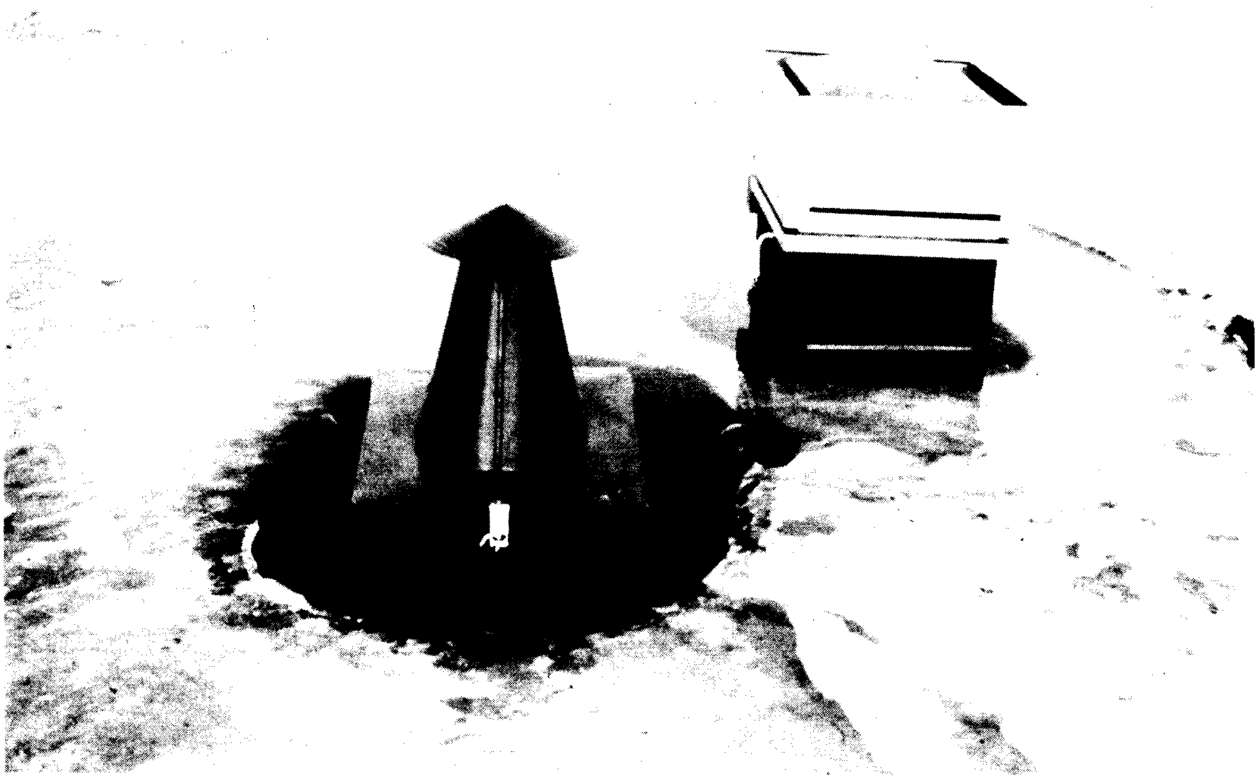


FIGURE 5 - SEVERE PONDING AROUND A VENTILATOR AND ROOF SHUTTER. WATER LEVEL HIGHER THAN THE UPSTAND OF THE ROOFING. LEAKAGE.

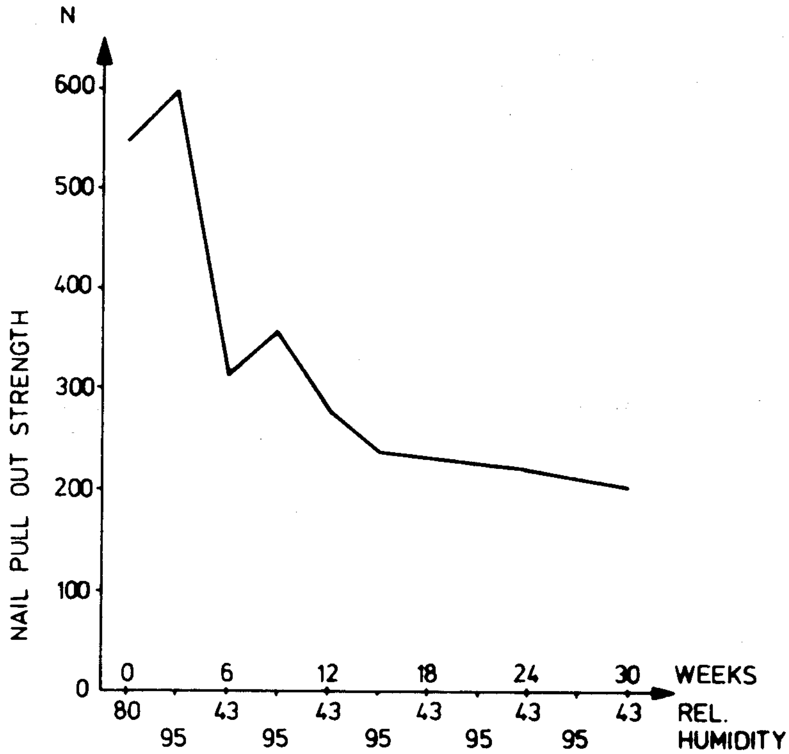



FIGURE 6 – NAIL PULL OUT STRENGTH FROM WOOD, STORED ALTERNATIVELY IN 95% AND 43% RELATIVE HUMIDITY WITH CYCLING PERIODS OF THREE WEEKS. 1 N ≅ 0.2 lbf.

FIGURE 7 – NAIL PULL THROUGH STRENGTH THROUGH DOUBLE ROOFING FELT. LEFT: RAG FELT. RIGHT: GLASSFIBRE FELT. THREE DIFFERENT MAKES A B AND C. 1 N ≅ 0.2 lbf.

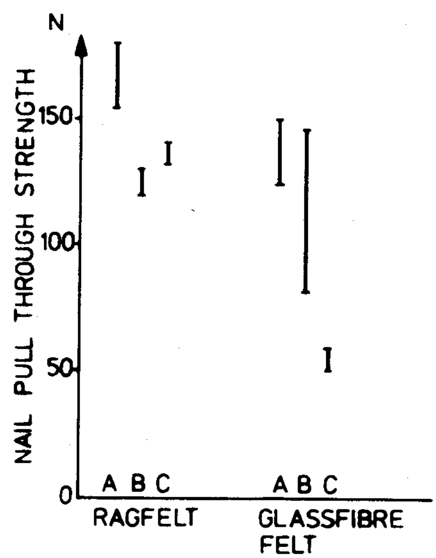


FIGURE 8 - FOUR METHODS OF TESTING RESISTANCE TO PUNCTURING. A. PUNCTURING BY QUARTZ GRAINS ON A RUBBER SUBSTRATE. B. NAIL HEAD INDENTATION. C. WEDGE INDENTATION, LONG TIME LOAD. D. IMPACT FROM A FALLING STEEL BODY.

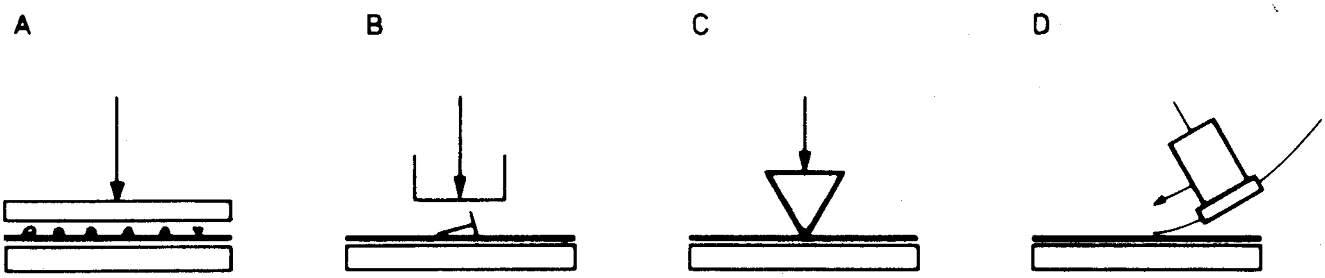



TABLE 1 - THERMAL REQUIREMENTS ON BUILDING IN SWEDEN FROM JULY 1977.

| Temperature level in rooms | Total heat transfer coefficient U-value $W/m^2 K$ ($BTU/ft^2 F$) | | Approx. corresponding thickness of insulating layer on a metal deck mm (inch) | |
|---|---|---|---|---|
| | N* | S* | N* | S* |
| Heated to >18°C (64°F) | 0.17 | 0.20 | 230 | 190 |
| (Dwellings, offices, etc.) | (0.054) | (0.063) | (9") | (7½") |
| Heated to 10 - 18°C (50 - 64°F) | 0.47 | 0.47 | 80 | 80 |
| (Industries etc.) | (0.15) | (0.15) | (3") | (3") |

*N = Northern Sweden
*S = Southern Sweden