THE WAY AHEAD FOR FLAT ROOFING

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When BRE Digest 144[1] was published in 1972 it confirmed what many people already knew: that flat roofs in the United Kingdom were not performing satisfactorily.

The phenomenon of premature failures in flat roof waterproofing was under investigation by researchers in many parts of the world, but there was little general appreciation of the extent of those failures or their true causes.

In 1974 an international symposium on flat roofs and roofing, held at Brighton, brought together a wide selection of people concerned with the design and installation of roofs and roof coverings. Much has since been learned about the complex nature of roof failures and considerable progress has been made towards restoring confidence in the flat roof as an acceptable form of construction.

This paper seeks to identify the major lessons learned and to suggest possible developments over the next decade.

CAUSE AND EFFECT

Some early work by Moseley[2] in the U.K. and Martin[3] in Australia identified substrate movement as a major cause of failure evidenced by splitting of the waterproof layer: later work by Cullen and Mathey in the United States, however, presented no less than 20 attributes believed to have significant impact on the service performance of a roof covering.

Our own investigations, over a period of 14 years, indicate that failure is seldom, if ever, the result of one factor; rather it is a compound of inadequate materials, poor design, and bad workmanship.

IMPROVED WATERPROOFING MATERIALS

From earlier investigations of membrane failures it was easy to conclude that radical improvements in bituminous felts were urgently needed, and laboratory research indicated improved tensile strength as a priority.

Development of Bituminous Membranes

Approximately 75 percent of flat roof waterproofing in the U.K. is achieved with built-up bituminous felts. The bulk of the remainder is mastic asphalt.

In response to criticism of bituminous felts made to British Standard 747[6], manufacturers in the U.K. progressively developed their products to achieve greatly improved tensile strength.

One of the pioneers in this field was D. Anderson and Son of Manchester who developed a range of high performance membranes based on a polyester fleece. Bitumen coatings ranged from oxidized bitumen to polymer-modified bitumen; the bitumen coating could be modified with atactic polypropylene (APP) to allow membranes to be applied with a gas torch, thus dispensing with the roof-top bitumen kettles associated with traditional "pour and roll" techniques.

These new membranes rely upon a closely controlled relationship between the properties and characteristics of the core material, which imparts strength, and the bitumen, which provides waterproofing and weather resistance. Figure 1 indicates how far they out-perform BS 747 felts under test conditions.

Other manufacturers have since developed similar materials and the British Standard is now being revised to incorporate bituminous felts based on polyester fleece cores of specific weights. Eventually it is to be hoped that a new British Standard can be developed based upon performance criteria for bituminous membranes, but much work must first be done to establish suitable test methods.

Another early development[7] was the modification of polymeric material, such as chlorosulphonated polyethylene, with bitumen to produce a hybrid material with some of the physical characteristics of a thermoplastic sheet.

	Typical Value of Load at Failure		
		High Performance Felt	
Test	rag based felt to BS 747 (1.8 Kg/m²)	polyester core and blown bitumen	polyester core & copolymerized bitumen
Compression Felt laid on 40 Kg/m³ fibre board; load applied through 10mm drain steel ball	80 Kg	60 Kg	50 Kg
Tension 50mm strip at constant rate of extension (INSTRON)	400N(L) 210N(T)	1230N(L) 490N(T)	1059 N(L) 1039 N(T)
Bursting 50mm drain disc (MULLEN)	500 KN/m²	3.860 KN/m²	3.033 KN/m²
Tearing (ELMENDORF)	89 N/cm	250 N/cm	230 N/cm
Fatigue Felt bonded across a butt joint and cycled 5 times/min from 0-2mm gap at 23 °C	2 cycles failed	10.000 cycles no failure	10.000 cycles no failure

Figure 1 Comparison of test results on BS 747 and high-performance felts

An inherent advantage claimed for all these bitumen-related membranes is that they are "bitumen-compatible" and can be applied by established methods using existing labor, skills, and tools. Since 1973 they have secured an increasing share of the U.K. market as shown by Figure 2. In addition, they are widely exported, and similar materials are now available around the world.

Development of plastics

In parallel with the development of bituminous membrane materials a great deal of work has been undertaken by the chemicals industry to promote sheet materials loosely described as plastics. The waterproofing and weathering properties of such materials have been well known for a number of years. In Germany they have been used extensively below ground since 1938 and on roofs since 1953. If they are evaluated merely by reference to their tensile strength they appear generally superior to most bitumen-based materials. In America membranes now account for some 40 percent of the roofing market with EPDM and PVC taking the lion's share. Why is it then that plastics have so far failed to make a significant impression in the U.K.? *(Figure 3.)*

ACCEPTANCE OF SINGLE-LAYER PLASTICS MEMBRANES

There can be little doubt that the strength of the U.K. bitumen roofing industry militates against the adoption of other materials and techniques. In order to obtain a significant market share the plastics manufacturers must make the professional specifier more aware of their products, provide more specific product information, and ensure there are enough trained roofers to provide a competitive service. It is not sufficient merely to claim superior tensile strength or tear resistance. The specifier needs to know what the materials are, how they are handled, jointed and applied to roofs and how good performance can be assured.

Identification of Plastics Materials

Perhaps the most important step towards acceptance of plastic membranes would be removal of the confusion caused by a proliferation of products with unfamiliar names and confusing properties. The specifier needs a clear definition of the new materials, preferably in generic terms, together with comparative details of their performance and full information on application techniques including seaming methods.

A Basis for Classification

Hechler[8] proposed, as a basis for generic classification, that plastic membranes be grouped under three broad headings:

- thermoplastic
- elastomeric
- modified bitumen

The first group included those sheets, such as PVC, which are deformed by heat. They can be melted by the applications of heat or solvent and thus can be readily fused together. The second group included those materials commonly referred to as synthetic rubber, such as EPDM and butyl rubber. They are characteristically crosslinked or vulcanized and cannot be plastically deformed.

The third group covers a wide range of sheet materials based on a blend of bitumen and various types of polymer in varying proportions. For example, bitumen modified by the addition of atactic polypropylene or ethylene copolymer bitumen (ECB).

Unfortunately these distinctions are not clear-cut. For example chlorosulphonated polyethylene (widely marketed under the Dupont trade name Hypalon) does not become crosslinked until it has aged for several months. Thus it is a thermoplastic sheet as manufactured but subsequently becomes an elastomeric one. The consequent changes in its physical properties affect jointing techniques.

Furthermore, within each group there are considerable differences in product formulations which are adjusted to product materials with specific properties, such as UV resistance, extensibility, color etc. Nonetheless, the broad generic definitions are helpful as a basis for comparative assessment, and we have used them to prepare a comparative analysis of plastic roofing membranes currently available in the U.K.[9] Different grades of materials are available within each group. For roofing applications one commonly finds both reinforced and un-reinforced sheet and sheet with or without a backing material. Such differences relate to the different methods of application.

Product Specifications

It must, however, be pointed out that plastic membranes are not made by the companies that produce the basic chemical building blocks (chlorinated polyethylene, chlorosulphonated polyethylene, polyvinylchloride etc.), but by intermediate manufacturers who are responsible for measuring, mixing and calendering the materials, and who then sell the sheet to roofers. It is thus obvious that one PVC sheet can vary from another in much the same way as two cooks using the same flour will produce vastly different pastry!

The problem is well illustrated by a brief outline of the process for making an EPDM roofing membrane. Ethylene-propylene rubber requires peroxide-free radical catalysis for cure. EPDM is a terpolymer, the diene monomer being edhylidene norbornene (ENB). Curing is commonly achieved by the inclusion of sulphur with several activating agents. A typical mix recipe is shown in Figure 4. The ingredients must be carefully measured and compounded and allowed to age for several hours before being crumbled and passed through feed mills and calenders to emerge as raw sheet which is cooled and vulcanized in a steam curer.

Product Standards

With such sophisticated formulations and production methods it is evident that product standards will be difficult (if not impossible) to establish. But the absence of standards is possibly the greatest barrier to wider adoption of new materials.

In the U.K. this problem is under consideration by the Flexible Roofing Association[10], established in 1978 with the aim of fostering responsible manufacture and installation of polymer-based roofing membranes. Work is also being done at the international level, under the auspices of a joint CIB/RILEM Committee on Single-Layer Roofing[11], to establish material definitions, standards, and methods of testing and evaluation. Subsequently the committee will develop recommendations for single-layer waterproofing materials and systems based on realistic criteria.

Product Assessment

Much work has already been done on the assessment of single layer roofing materials, notably by Martin[12] in Australia who investigated tensile strength and bond strength in a number of thermoplastic, elastomeric, and bitumen impregnated membranes.

More recently Rosenfield[13] has reported on the first stage of field trials in which PVC roofing will be monitored for performance over a 10-year period. This work already has identified certain material limitations and practical problems to be overcome in site applications.

Application of Single-Layer Roofing

Unlike the bitumen-based materials, which can be applied by traditional installation methods, plastic membranes require roofers to learn new skills, to adopt new techniques and to buy new equipment.

Manufacturers of plastics materials must recognize the particular conditions that occur in the construction industry and alert users to the risks of placing incompatible materials in harmful juxtaposition. Some plastics materials will lose plasticizer to styrene-based insulants and some are not compatible with bitumen. Such considerations are vitally important, especially when more than 50 percent of U.K. roofing is currently retro-fit.

Technical Trade Literature

With a few notable exceptions (e.g., Dynamit Nobel) technical trade literature on the new plastics membranes is of very poor quality. Products are seldom identified in an unambiguous way; comparative data on performance are not provided, obscure test standards are often referred to without explanation and little or no information is given on costs and availability.

This situation must improve, and manufacturers are recommended to consider BS 4940[14] on the subject of technical information for specifiers.

IMPROVED DESIGN

Compared with the situation in the early 1970's, we now have available a range of high performance membranes which have been engineered to meet roofing conditions. Improved membranes are not, of themselves, sufficient to avoid roofing failures and designers must address themselves to more fundamental consideration of the roof element.

Condensation

BS 6229 describes condensation as a principal cause of flat roof failure and provides data for its control, including outdoor and indoor psychromtric conditions for the U.K. Using the data to assess typical warm deck constructions designed to meet U.K. thermal insulation standards for dwellings we can show them to be at risk for condensation *(Figure 5).*

In any flat roof construction the waterproof membrane is inevitably the most resistant to water vapor pressure. Typical resistance figures for waterproof membranes are:

100 MN.s/g for built-up felt roofing

156 MN.s/g for chlorinated polyethylene*

compared with 15 MN.s/g suggested by BS 2972[16] as an appropriate figure for a vapor barrier and 47 MN.s/g for 100mm thickness of extruded polystyrene foam.*

Other Design Considerations

The Standard recognizes the established types of flat roof, namely cold deck, warm deck, and inverted. For all types it recommends:

- isolation of roof coverings from movement in the supporting structure.
- provision of adequate slope to ensure run-off from all surfaces.
- provision against calculated wind up-lift.
- protection of the waterproof membrane.
- provision of access for regular inspection and care.

Isolation of the Membrane

As already mentioned, early research identified substrate movement as a cause of flat roof failure, especially where membranes were fully adhered. If we can now predict condensation on the underside of the membrane in warm roof designs there must be grave doubts about the long-term effectiveness of *any* fully adhered system of waterproofing.

Membranes which are non-attached, mechanically attached, or partially adhered all allow substrate movement to occur without damage to the membrane, allow thermal movement of the membrane, and in addition, avoid moisture breakdown at the adhesive line. It has been common practice in the U.K. for more than 20 years to spot-bond built-up bitumen membranes by the use of a perforated and gritted first layer. The system was developed to allow dispersion of entrapped construction moisture which might be vaporized by solar radiation. If pressure relief is provided at edge details, this construction has been shown to work well in practice.

Vapor Dispersion

Some suppliers of single-ply roofing suggest that their materials are sufficiently permeable to avoid the buildup of moisture beneath the membrane. Two different concepts are involved here. Construction moisture trapped beneath a membrane may be vaporized as described above and that vapor may be dispersed beneath a non-adhered membrane. If sufficient pressure is maintained for sufficient time *some* moisture *may* be driven through the membrane.

For pressure arising within the building it is, in our view, impossible to achieve any measurable relief at the cold side of the insulation in a warm deck roof since, at that point, the dewpoint temperature already has been reached. Vapor dispersion may be possible at the warm face of the insulation and it is interesting to note Tobiasson's[17] suggestion that casual venting of compact roofing systems is unavoidable and beneficial. However, what is good for vapor dispersion may not be good for wind uplift!

Aerodynamics and Wind Uplift

Design data on wind forces are provided in national codes but relatively little is known of the performance of single-layer roofing under conditions of high wind pressure. We have reported on one roof failure involving a Hypalon membrane fully bonded to polyisocyanurate boards on the roof to a swimming pool[18], and described the use of vents to achieve equalization of pressures across the new membrane. Kelly has suggested[19] that the aerodynamic forces of single-layer roof covering may be resisted by suitably designed mechanical fastenings allowing the membrane to balloon or by the use of pressure relief valves.

**Source: Dow Chemical Company Limited*

Membrane Protection

It is now widely accepted that all forms of waterproofing will give greater service life if protected from mechanical damage and direct weathering. This has been a major consideration influencing the wider adoption of inverted roof designs. When one evaluates the inverted roof using the data from BS 6229, it is relatively easy to ensure that condensation does not occur beneath the waterproof membrane. By moving the most efficient vapor resistant layer to the warm face of the insulating layer we are conforming to the basic rule of designing "vapor diffusion open" structures.

In heavyweight constructions, where slabs of ballast are used as the topmost layer, wind uplift is seldom a problem with inverted roofs. However, designers seeking to extend the principle to lighter structures have forced the development of lightweight "upside down" roofs, and such designs are now engaging the attention of researchers in the U.K. (Newberry) and Canada (Kind and Wardlaw).

A New Approach to Design

From the lessons of the past it should now be possible to adopt a systematic approach to flat roof design. To do this we must consider:

- where the building is located
- how it will be used
- what the form and shape of the roof is
- what thermal performance is required

From such information we can proceed to postulate alternative design solutions involving cold, warm or inverted deck, non-attached, mechanically attached, fully adhered, or partially adhered membrane and then proceed to select the most appropriate combination of insulation-membrane protection to ensure appropriate performance.

REFERENCES

[1] BRE Digest 144: "Asphalt and built-up felt roofing: durability."

[2] Moseley BN: "An explanation of built-up roofing tension splits." 1964 London: British Standards Institute

[3] Martin KG: "Tensile strength of bituminous roofing fabrics." 1964 Melbourne: CSIRO

[4] Cullen WC & Mathey RG: "Preliminary performance criteria for bituminous membrane roofing." 1974 International Symposium on roofs and roofing. Brighton, U.K.

[5] Potter J: "A practical guide to durable flat roofs." Second International Symposium on Roofs & Roofing. Brighton, U.K. 1981.

[6] British Standard 747: 1977 "Specification for Roofing Felts."

[7] Edward RM & Lingard DJC: "The development of bitumen polymer roofing systems." 1974 International Symposium on Roofs and Roofing, Brighton, U.K.

[8] Hechler. Dipt. Eng. H: "Flat roofs in the Federal Republic of Germany." 1974 International Symposium on Roofs & Roofing. Brighton, U.K.

[9] Potter J: "Analysis of single layer roofing in the U.K." 1984. Private papers.

[10] The Flexible Roofing Association: 125 Queens Road, Brighton, Sussex, BN1 3YW.

[11] Joint Committee on Single-Layer Roofing: Secretary WJ Rossiter Jr. National Bureau of Standards, B-348 Building Research, Washington DC 20234. USA.

[12] Martin KG: "Assessment of plastics sheets for waterproofing roofs." 1975. Melbourne: CS 1RO

[13] Rosenfield MJ: "Construction of experimental polyvinyl chloride (PVC) roofing." 1984 Champaign, Illinois. US Army Corps of Engineers.

[14] BS 4940:1973. "Recommendations for the presentation of technical information about products and services in the construction industry."

[15] BS 6229:1982: "British Standard Code of Practice for flat roofs with continuously supported coverings." London, British Standards Institute.

[16] BS 2972:1975: "Methods of test for inorganic thermal insulating materials." London, British Standards Institute.

[17] Tobiasson W: In proceedings of the 6th Conference on Roofing Technology, sponsored by the National Bureau of Standards and the National Roofing Contractors Association.

[18] Potter J: "Insulating and Waterproofing a Swimming Pool Roof using Plastics Materials." Second International Symposium, Liege, Belgium, 1984.

[19] Kelly T: "New technology for roof installation." Second International Symposium, Liege, Belgium, 1984.

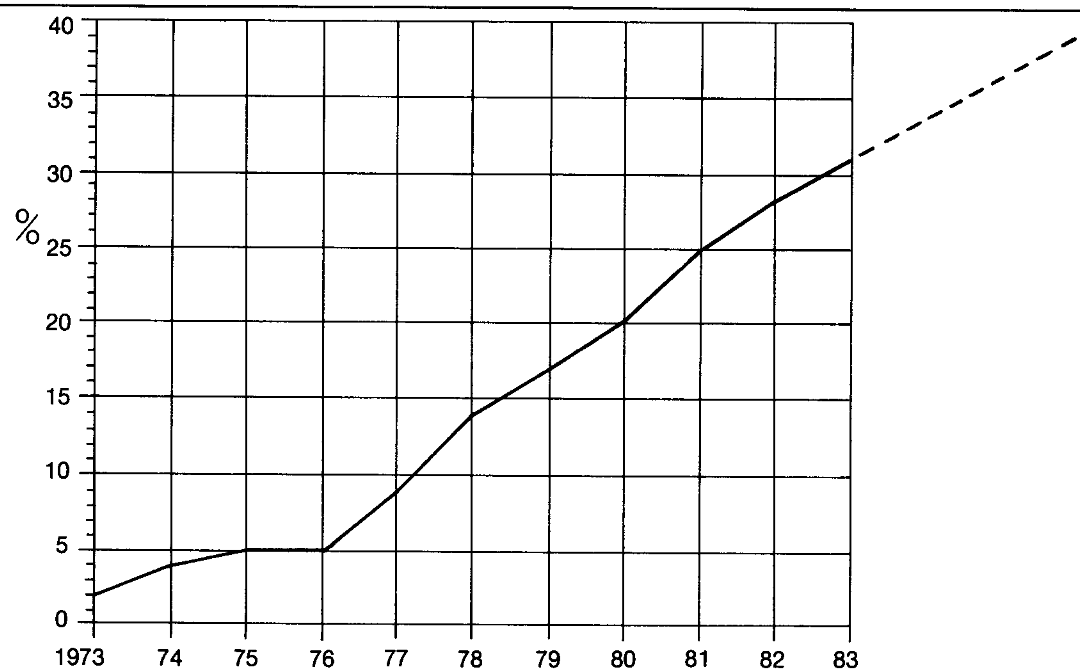

Figure 2 *Proportion of U.K. roof area waterproofed with high-performance membranes*
Note: 1973 = 24% polyester-based *1984* = 95% polyester-based

Material	1977	1980	1983
Mastic asphalt	27.5	25	20
BS747 felts	66	65	40
All high performance felts	6	9	37
Single layer plastics	0.5	1	3

Figure 3 *Flat roof waterproofing material: percentage share of U.K. market*

112.0 parts EPDM *
67.0 parts carbon black
18.0 parts Mistron Vapor
90.0 parts Sunpar 2280
0.3 parts Sulphur
0.5 parts Ethyl Tuex
0.5 parts Tuex
1.2 parts Stearic acid
0.9 parts Zinc oxide

Blend 50:50 of Dupont Nordel 1040 & 1070.

Figure 4 *Typical mix for an EPDM roofing membrane*

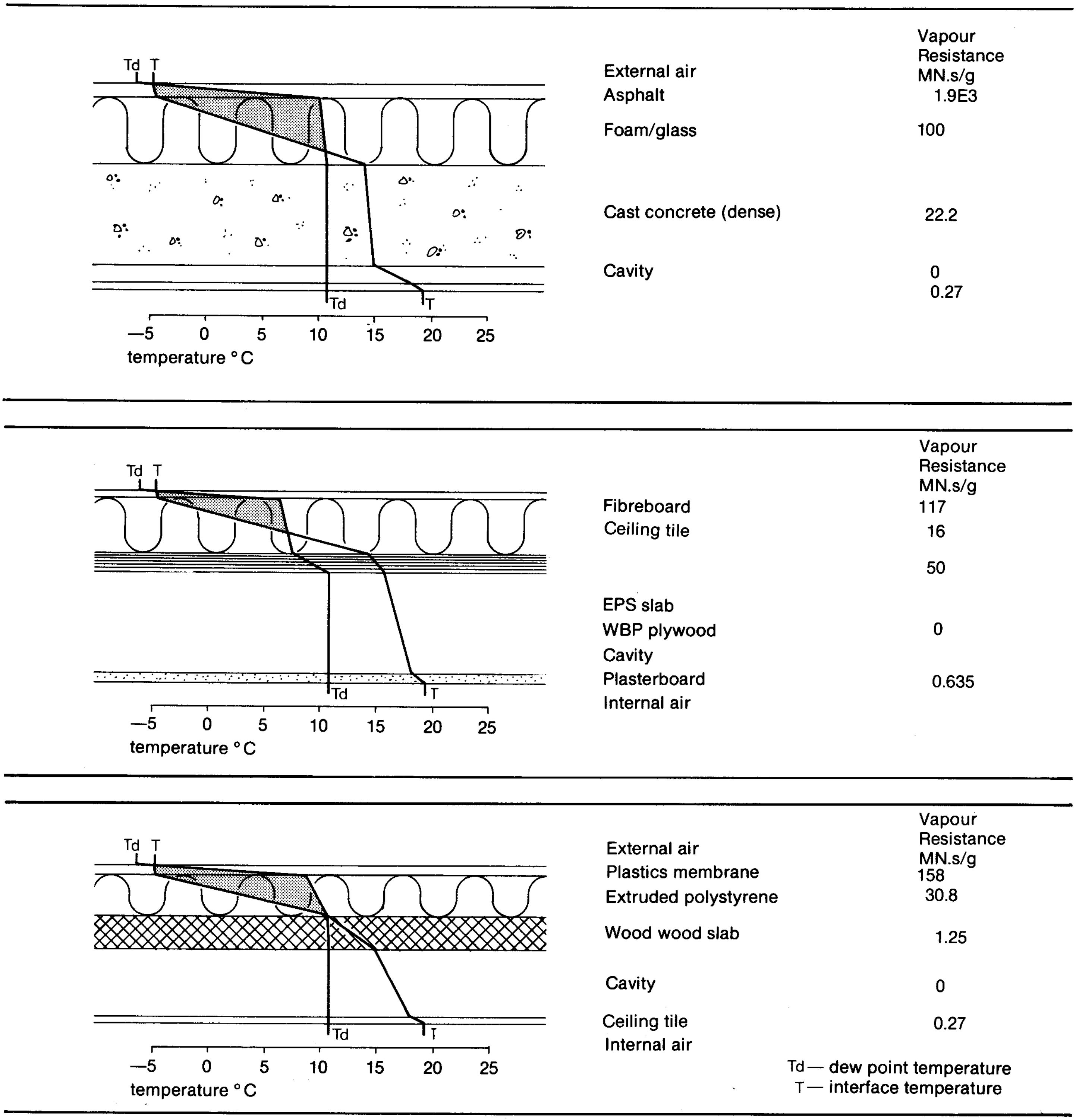

Figure 5 Condensation predictions in typical warm roof conditions