

ROOFING IN EUROPE

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I would like to begin with a few scene-setting remarks about Europe.

First, despite the Common Market, Europe is still a patchwork quilt of separate countries with differing local and imported building materials. This has led to differing traditions of skill and habits of construction, and without a common language to facilitate pan-Europeanism in building technology.

Historically this has resulted in quite sharp architectural differences in handling weather-casting systems of sloped roofing obvious to every traveller, and the demands of historic conservation keep the traditional skills and materials alive. But even in the less obvious early development of waterproof roof systems there were national differences. More recently the advent of multi-national roofing industries and the almost universal need to conserve energy have been strong internationalizing influences, but even these have not prevailed entirely against some national prejudices and protectionist instincts.

There are, of course, climatic differences familiar to everyone, but these exist in any large land mass. What I have been delineating is the contrast between an area such as America north of the Mexican border, where one language and much economic commonality prevails, and Europe, with a moderately smaller land mass but roughly similar population. These obstacles do not ease my task of reporting on European roofing.

WEATHER-CASTING SYSTEMS

The houses of Europe are generally roofed with rain-shedding tile systems, traditionally of clay, because good clays are abundant all over Europe. However, cement has captured a share of the market in some areas during the past 50 years. The wood shingle of North America never took hold in Europe. Nor have its modern, more durable and less fire-sensitive substitutes found much of a market.

The tiles are moulded to hook on to battens crossing between rafters. Generally only a proportion are nailed in place, the remainder being restrained by lapping and by gravity. In the wetter climate areas a bituminous felt is usually fixed over the rafters before the battens are placed to act as a fail-safe water-proofing device and wind-break. In colder areas one can find a tradition of timber-boarding and felt over the rafters before the battens are placed. The demands for energy conservation are now commonly met by placing insulation at ceiling level and ventilating the roof space to avoid dampness in timbers because of condensation.

Some effort and ingenuity have been devoted in recent years to producing weatherproof systems at low slopes because of architectural demands.

Tiling is expected to have a life of at least 40 to 60 years, even in the hardest of the freeze-thaw climate areas, and it can last much longer.

Sheet metals, copper, lead, zinc, aluminum and stainless steel are a second category of weather-casting roofings. Mostly they are used on buildings other than houses and can do their job successfully even at very shallow slopes. Their popularity shifts with the movement of world or national commodity prices. This has generated quite a lot of effort by any threatened sector of the industry to find ways to reduce costs in order to hang on to its place in the roofing market.

One endeavour by copper and aluminum interests has been to apply a very thin sheet of metal to a bituminous felt as a carrier. The aim is to secure the appearance of metal in a built-up roof without paying for much substance. In practice it has been laid both by metal-working techniques and by the built-up roofing process, as if it was not clear which kind of cross-bred animal it was. Architects have not warmed to it and it has had problems of corrosion in seams and poor adhesion at laps.

Another technique, exploited especially by aluminum interests, has been to find ways of using the metal in long strips where mechanization can reduce manual labor. Metals, especially aluminum, have comparatively large coefficients of thermal movement. It is not very clear just how this is accommodated in the long-strip technology, nor whether the restraints embodied have any adverse effect on life expectancy.

Presumably it is by local give-and-take along the strips. I would expect this to cause some embrittlement and perhaps lead to an increase in corrosion sensitivity. Corrosion is of course the great enemy of metals, especially in damp climates and where there is atmospheric pollution. It is an active area of research today in Britain and continental Europe.

Zinc had a long period of popularity in France and Germany, but this appears to have diminished in recent years.

Rolled lead and stainless steel seem to be battling for a particular market, certainly in Britain where lead has had a very long run. It has been the preferred material for ancient church roofs for so many years that it seems almost to have biblical authority. Today its market value second-hand is such that no accessible church roof is safe from theft, because stripping is an easy and quiet operation. This has prompted considerable interest in stainless steel among conservation architects; it appears to have a longish life (though information about this is not yet clear) and an appearance not unlike lead.

All of these metals, except probably stainless steel, seem to have a realistic life expectancy of the same order as tiling. But in saying this I offer a reminder of the distinction be-

tween rolled and cast lead. The two are different in their behavior and life expectancy, despite their similarity in appearance. I understand that the rolling process results in a less homogeneous and less stable crystalline structure than the cast material. It is the latter which has been and is still used on the great cathedrals and ancient parish churches where they can afford it. Cast lead can give several hundred years of life in situ, failing generally only by some form of damage to its support system.

On the whole the weathercast roofs have behaved well in the past and still do. Their architectural popularity is increasing as a result.

FLAT ROOFING

Now let me turn to the more troubled picture of flat roofing, where market battles are being fought in Europe between old-established materials and techniques, the newer forms of bitumen sheeting, and the single membranes of PVC, butyl, and so on. Sometimes insulation is below the membrane as a sandwich between it and the vapour check, and sometimes it is above, in the so-called 'inverted' or protected membrane arrangement. Perhaps I should deal with the latter first, because it influences one's views about individual materials.

So far as I can see, the inverted system, where the membrane is protected by a lightweight insulation held in place against wind uplift by gravel or paving, is going to prevail wherever the roof deck is sufficiently substantial to take the load. This, in any case, is little more than the traditional 18 or 20mm of a bituminous waterproofing membrane with its insulation and vapour check.

I think that European designers, with an exception I will mention later, expect this protected membrane system to prevail also on less substantial decks framed in timber or formed in profiled metal on the structural frame commonly used on industrial buildings. But before that happens on a substantial scale it would seem that we need to have lightweight, weatherproof insulations that can be kept in place by adhesion, and which have an attached wearing surface that can stand up to abuse by maintenance people. It is an active area of development at present, though we have seen some surprisingly impractical efforts.

It will also require adequately stiff decks. Timber presents no problems in this respect but profiled metal has been causing some difficulties. In Britain and continental Europe it is common practice to fix it to a steel supporting frame by shot-firing, using a single shot at each nodal position. It seems to be assumed that this will be secured and contribute sufficiently to the stiffness of the decking to prevent excessive deflection.

Perhaps such decks seem satisfactory when the roofing has just been laid. But in practice, vibration in wind and the weight of people walking the roof for inspection or maintenance work enlarges the shot holes so that deflection becomes easier and easier. We have examined cases where the weight of a man on such a roof caused a sag of the order of 35mm in profiled steel over a span of only 1.2m. No weatherproofing system is likely to retain its integrity where the deflection of the deck is excessive, but such realities as these do not appear to have been foreseen by code drafters or, curiously enough, by roofing subcontractors. It would seem sensible to require that metal decking be stiff enough without the aid of fixings not to sag significantly in these

real-life circumstances, and that the fixings should simply resist wind uplift.

MATERIALS FOR FLAT ROOFS

Mastic asphalt

In Europe this name identifies a material found in natural form in some parts of the world—Trinidad, for example—and which chiefly consists of finely divided limestone bound together by bitumen. For use as roofing it is extended up to 50 percent by additional finely ground limestone, and by bitumen made either from naturally acidic oil or oil artificially acidified, presumably to produce a more homogeneous chemical blend with the alkaline aggregate.

Mastic asphalt is heated on site to controlled temperatures and applied by trowel in at least two coats totalling about 18-20mm thick onto a thin, open-textured, so-called sheathing felt overlying the deck. The felt serves two main purposes: modest reinforcement of a material weak in tension and the avoidance of patchy adhesion. The latter is important to avoid uneven thermal stressing during daily temperature changes and to allow the dispersal of moisture vapour coming from or through the deck which otherwise may concentrate and cause blisters.

Asphalt in this form acquired an enviable reputation as the high-quality, durable flat roof weatherproofing in Britain and a number of other difficult climates in Europe. This seems to have been largely a result of circumstances accidentally favoring its behavior. It was mostly used on concrete slab roofs not having much thermal insulation, so that the escaping heat from the building plus the large thermal mass of the concrete limited the seasonal and diurnal temperature range it experienced. With the advent of higher insulation standards the added insulation was usually placed on the slab, preventing it from acting as a heat sink. Therefore, the temperature range the asphalt experienced increased by perhaps 100 percent. Also, the insulation provided neither the sturdiness needed to avoid damage by impacts, nor the lateral strength to resist the enhanced thermal restlessness induced by the increased temperature range. Being in reality only a stiff liquid, expanding when heated but with not much ability to retract on cooling, asphalt has suffered a troublesome rise in the failure rate.

Some asphalts suffered much more severely than others. In the investigation of failures we have observed that those that suffered most were those in which the proportion of the finest aggregates in the mix was high, coarse aggregate was low, and the percentage of bituminous binder was also low. This is a recipe for a weak material because the grading is poor and because a high percentage of fines needs a high percentage of the binder. The limiting percentages of each are included in standards, but the acceptable ranges are broad. It appears that they need reconsideration for modern usage. In our investigations the materials all met the relevant standard, but they all failed.

These misfortunes have damaged the reputation of this valuable form of weatherproofing, capable of a very long life when used in appropriate circumstances. In the inverted roof arrangement, where it would be laid directly on a deck and be protected from temperature extremes, I see no reason for it to fail within a century or more though skirtings and other upstands would no doubt need earlier attention. Asphalt examined recently that has been under roof gardens for nearly half a century has been found to have suffered no

apparent deterioration.

Built-Up Roofing

In Europe the built-up membrane was a lower cost competitor to asphalt and was assumed to have a shorter life—20 years for a good quality job.

The materials used were termed bituminous felt. In fact they were, and are, more than felts. They were factory-made composites embodying a fibrous reinforcement of some kind in bitumen, modified and processed to produce continuous strips 2-3mm thick with non-tacky surfaces. Any such felt would be nominally waterproof in itself, but it was laid and built-up, usually in three layers, by unrolling the material onto successive flood coats of hot bitumen. Eventually the top felt was one with a factory-applied mineral finish in a limited range of colors, or a plain felt over which stone shippings were laid in another flood coat of bitumen. The total thickness, excluding chippings, was usually 13-18mm.

It is well known that such materials gradually lose volatiles from the surface and try to shrink. Unlike mastic asphalt, any shrinkage has the benefit of the reinforcement to help it develop. This can do damage at laps and upstands, though it may take quite a few years to fail.

I have closely watched some felt roofs of the type described on my own house and garage. These all survived 30 years before leakage occurred, despite some severe blistering. When failure occurred it was on one roof only, and chiefly due to some movement in a rendered woodwool base on timber framing. The remainder are intact.

This is an exceptional performance, due more to luck than judgment on my part in the 1950s. Failures occurred widely in Britain and mainland Europe in much shorter periods but, in our experience, this was due chiefly to variable workmanship (to which the system is sensitive), difficulties at skirtings and around pipes, misbehavior of the base in ways which had not been expected to be damaging, or to moisture vapour from inside the building causing severe blistering. As with asphalt, the laying of built-up roofs directly on insulation led to thermally-induced troubles for which these products had never been engineered. Often the membrane itself was otherwise sound.

Thus both mastic asphalt and built-up roofing acquired the reputation of being accident-prone, and flat roofs began to be viewed very skeptically by designers and potential building owners within the past 10 years or so. Even the merits which I think most designers see in the inverted roof could not wholly prevail. In France, for example, I understand that the prejudice against extruded polystyrene is such that inverted roofs are effectively precluded at present, despite their logical soundness and excellent performance thus far.

Personally, I think both the asphalt and built-up roof industries did their homework poorly. The causes of faults were more in the usage than in the products themselves, but it seems that the industries concerned were unable to focus adequate research resources upon this aspect of their products' behavior. I am reasonably certain that had they done so, or if the public building research resources had been directed in sufficient strength to the problem, we would not have had as much poor performance as we did, and we would not have to surmount the resistance to flat roofs that has developed.

Realistically, the requirements for increased insulation

and the generally pervasive innovation that took place in building were the chief causes of the misfortunes. But the industry's leaders do not seem to have lifted their gazes far enough from their individual products to take the collective research action that was needed. The failure to act collectively in this way has harmed everyone in the industry and protected none.

However, there seems to have been a silver lining to this particular cloud, for it has certainly stimulated the development of better felts, using better reinforcement and newly odified bitumens. They are generally formed as thicker materials, fully 3mm thick. In continental Europe they seem generally to be laid by torching rather than by flood coats of hot bitumen. The torching is done with a long-handled blow torch, which the operative sweeps across the downward face of the material as he slowly moves his roll forward.

It is claimed, at least for some of these products, that they are durable enough to give a pretty good performance as single membrane roofings. However, their thickness has at least one disadvantage: laps are thick, especially where a cross-lap meets a lengthwise lap. This seems likely to trap pockets and runs of air that could begin to generate blistering and create bumps that can be troublesome if one is laying an inverted roof. I am personally attracted instead by the idea of laying these thick sheet materials in two layers butt-jointed, with the joints well displaced, though special care is needed where a long butt joint runs over a crossing joint. Another possibility would be to lay a single layer butt-jointed and top it off with a sacrificial cap sheet, though it would presumably have a much shorter life.

An attractive feature of at least some of these membranes is that the torched material can be moulded and welded well around pipes and other upstands. Architects have to help here by bringing pipes up in sensible places where the operatives can do a good job on all sides.

I hope that with these new materials the industry can achieve the reliability that will offset some of the prejudices that have developed about flat roofs, but it will take time. Vigilant, open study of the causes of any failures is also needed, and I do not see this on the horizon.

Single Membranes

This term describes non-bituminous membranes such as butyl or PVC sheet. In Europe their popularity varies from country to country, apparently depending a good deal on the marketing strength of the respective manufacturers. Butyl appears to have been popular in Germany, for example, but it did not appeal much in Britain, perhaps because it requires a number of unfamiliar metal accessories. PVC sheet seems to have been popular in one or two Scandinavian countries but, again in Britain, designers are cautious because of reports of pinholing in inverted roofs, plasticizer migration, and coming adrift at laps and fixing points when used exposed over insulation. In addition, a single membrane has seemed to offer too little in the way of safeguards. A fault is immediately a leak, and seldom easy to find. Possibly pinholing and plasticizer migration in inverted roofs have been reasons for the recommended practice of putting a "fleece" of thin, foamed polyethylene below and above the membrane. To me this calls into question the use of the term "single" membrane, if two others are needed to make it work reliably.

Generally speaking, the experience of my firm in the investigation of failures, both in roofing and damp-course

flashing, has made us very cautious about products that incorporate appreciable amounts of plasticizers. It is difficult to know whether or not they will keep their place properly in these products. Plasticizers seem to be able to move within the product as well as to leave it and enter other materials in contact with it. In one case I kept a sample of a product from a failure in a large can on my office floor. Later I picked up the can to show it to someone and I found that the plasticizer had not only run out of the product but had perforated the can and damaged my nylon carpeting. That's a case of real instability.

SOME GENERAL OBSERVATIONS

Probably no aspect of European building has been subject to more innovation than flat roofing. From architects' points of view the roofing industries are subject to some justifiable criticism.

The vast majority of all buildings in Europe are designed by architects. For roofs they have to depend in the first instance upon the reliability of the products and upon the advice they get from manufacturers on the factors that could adversely affect the behavior of the materials. In both respects there have been shortcomings.

Here I must draw upon the personal experience of my firm as architect-investigator of failures. We have seen them in every form of roofing mentioned in this paper.

A particular feature of this kind of work has proved to be the extent to which we have had to penetrate causal factors of all kinds in the course of litigation. I will try to distill the most important of these.

First, the apparent narrowness of some of the scientific work done in commercial development laboratories. To put it briefly, products seem to be invented mainly by chemists but fail in real-life situations mainly by inadequately anticipated physics (leaving aside deficiencies of workmanship).

Second, and in particular, the increase in thermal insulation has had several kinds of destructive effects, depending on the type of insulation, its location in the roof, the type of deck, and moisture risks related to prevalent relative humidities indoors and out. These factors do not seem to have been understood quickly enough and well enough by some producers. It is not reasonable to say, as some do, that these matters are someone else's responsibility.

A third causal factor is the inadequate attention that seems to have been given to practical problems of roofing, such as sealing around penetrations, fastening of lightning tapes, capping of parapets, or the loads created by maintenance men jumping off their cleaning cradles. We have seen recommendations that maintenance men should wear soft-soled shoes on some types of roofs. Such suggestions are impractical to implement, and no roof should be so sensitive as to need them. One cannot litter a roof with the equivalent of signs saying "keep off the grass".

In sum, manufacturers and specialist roofing subcontractors must be able to see the roof as a whole system and put their products and their advice into that context. One way of envisioning a building is to see it as a system composed of a set of compatible subsystems. The roof is one of the most important of these and the roofing industry has to approach its role with this breadth and level of comprehension. It has a general responsibility for this element.

Having been thus critical, let me then also say that there has been a commendable endeavor by the roofing industry in the past three or four years to correct at least some of these shortcomings by producing broadly based literature in the form of books and manuals. One appreciates the educational effort involved and the attempt to be frank about risks. However, frankness obviously has sometimes to stop at manufacturers' doors, leaving designers to read between lines or to learn by their own and others' failures. In this sense, designers and the industry are in competition. Each has its own areas of liability.

At the same time it is necessary to keep in mind the reading and memory problems that confront designers. Large books can be commended for comprehensiveness but not often for technology transfer in the building industry. It is not a good reading industry. The authors sometimes learn more than their readers.

A key question is, "Who should now know what?" No one today can know all that is known or needs to be known about roofs or any other element in building. At one end of the operational chain are the professionals, architects and engineers, who should know the principles, but who cannot command all details. Occasionally they are blamed for not knowing them, however.

Next is the general contractor. By the term 'general' he, too, has to be excused from a command of detail. Today his job is more than ever managerial, though he has to be well-informed about technology. The real knowledge base now has to reside with the specialist subcontractors, and they have not, on the whole, yet recognized this role and accepted the breadth and depth of technology about which they must become knowledgeable. At present they are often protected by the form of contract that makes the general contractor liable for the performance of his subcontractors. I doubt if this makes sense any longer in what has now become a knowledge-based industry. I expect that before long this will be reflected in changes that will make the specialist subcontractors directly, rather than indirectly, liable in law, not merely for the products used but also, and this is important, for the acceptability of the circumstances of their use.

What I have just said derives more from my sense of the direction of legal logic than from detailed knowledge of contract law in all European countries. My schooling in legal logic, such as it is, comes from expert witnessing in construction technology for the past decade in a country where building contracts normally require an architect to organize the design of a building, supervise its construction, and certify completion and final accounts. It is a relevant second aspect of legal logic that judges seem increasingly inclined to emphasize that liability for delivering a good building to the client lies jointly with the building team as well as individually with the various participants.

Finally, let me return to the roof itself. Flat roofs rarely are expected to last more than 20 or 30 years, with the result that in any industrialized country we must expect something like half of the industrial effort to be spent on replacement. Griffin made this point clearly at the Brighton Conference a year ago. I then ask, have we, architects and roofing industry people together, thought through the implications of this, either for our initial installation or for our clients' ultimate interests in maintenance? I don't think we have, and I am sure we should do so.