Roofing - Past and Present

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NATIONAL RESEARCH COUNCIL
DIVISION OF BUILDING RESEARCH

CANADA

ROOFING - PAST AND PRESENT

BY

M. C. BAKER

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PREFACE

Members of the Division of Building Research are frequently called upon to deliver talks to professional groups and various associations. This paper brings together excerpts from four talks dealing with roofing and principally bituminous roofing on flat roofs given by Maxwell C. Baker, a Civil Engineer and Architect with the Construction Section of the Division.

The talks which form the basis of this report are:

- Talk given to Architects and Engineers of the Federal Department of Public Works at Ottawa, Ontario, 6 December 1963.

- Paper presented at the Annual Meeting of the Alberta Roofing Contractors Association at Calgary, Alberta, 21 November 1963, entitled "Dignity and Respect in the Roofing Industry."

- Paper presented at a meeting of the Master Sheet Metal Contractors Association of British Columbia at Vancouver, B.C., 26 November 1963, entitled "Research and Recent Development in Roofing."

- Paper presented at the Annual Meeting of the Newfoundland Association of Architects at St. John's, Nfld., 21 January 1964, entitled "The Architect and the Design of Roofing."

TABLE OF CONTENTS

TABLE OF CONTENTS (cont'd)

ROOFING - PAST AND PRESENT

by

M. C. Baker

HISTORY OF ROOFING

When we speak of roofing today, we are usually referring to bituminous roofs, as some form of bituminous material is involved for an estimated 85 to 90 per cent of the entire annual roofing coverage in Canada and the United States. This type of roofing has not always given good service and in recent years concern over problems has been expressed by architects, owners, manufacturers and tradesmen. One of the oft-quoted reasons why built-up roofing has not given satisfactory service is the difficulty of obtaining good workmanship. That this is a problem is pointed up by the fact that one of the stated objectives of Canadian Roofing Contractors Associations is the upgrading of the roofing tradesmen and the upgrading of the roofing industry. Through the years there has been a certain stigma in connection with roofing tradesmen - a tendency to consider that they are in a category lower than other types of tradesmen. At a roofers' meeting in Calgary in 1962, the idea was expressed by a Canadian member of a panel that children were not always proud of the fact that father was a roofer, and there appeared to be a feeling that roofing is not an industry in which anyone can operate with respect and dignity. It is interesting to consider how this situation has come about, by examining what has happened in roofing, what the situation is today, and what will probably happen in the future.

Romance of Roofing

Surely roofing must have been one of the earliest crafts in the world. Shelter has been one of the primary needs of man, and from the beginning he had to protect himself against the relentless forces of nature. We can imagine in the beginning that roofs were mere accidents, overhanging branches of trees for the tree-men, perhaps later tied together, and overhanging rock ledges for the cave-men, perhaps later filled in at the sides with stone and mud to exclude the elements. Perhaps pit dwellings came next, where a circular pit was dug into the ground and roofed over with branches and leaves. It must be assumed that somewhere in the march of evolution man discovered the watershedding quality of leaves which overlapped each other, and this undoubtedly led to the use of stone slabs and other local materials for roofs, laid in overlapping fashion. When such roofs leaked, the joints were probably stuffed with moss. As it was a living and growing plant, the moss filled the joints and formed an effective expansion joint and water barrier. Where stone was scarce, as in Egypt, clay had to be considered for building, and building blocks and tile were invented. The first clay roofing tiles are said to have been moulded by hand and shaped on the thighs of women artisans. Some Spanish tile even today has this characteristic shape, wide at one end and narrow at the other. The history of tile, slate, thatch and other roofing materials is extremely interesting and the roofer's craft with these materials is still alive in certain parts of the world.

One thing common to all these materials is that their use extends back over hundreds of years. Clay tile was used by the early Egyptians, and terra-cotta tile has been found in Greek ruins dating a thousand years before Christ. Slate was being used for other building purposes only a little later, and probably also for roofing. There are slate roofs in England that have been in service for over 1000 years. Records indicate that thatch for roofing was in considerable use in England seven or eight centuries ago, but its use probably originated much earlier. There are plenty of practical rules, based on experience, to guide the craftsmen, and with well-established application procedures no difficulties arise.

Connected with each of these materials there is a great deal of romance. What could be more romantic than the slater's trade where the slater works with Empresses, Princesses, Duchesses, Countesses, Ladies, Queens, Rags, and Peggies, which are some of the names used to describe specific sizes of slate. And who is not fascinated by the beauty, real or imagined, of thatched roof cottages found in the villages throughout the corn-growing counties of England, and which have come to be accepted all over the world as an essential part of the English country scenery. There are over 800 full-time thatchers in England and Wales still practicing this fascinating craft, maintaining and renewing old roofs, and thatching new houses.

Bituminous Roofing

How is it then that the trade of the tar or asphalt roofer is not considered a dignified craft? For the answer to this question, it is necessary to look back to the introduction of bituminous roofing, and what has happened in the roofing industry since that time. The waterproofing, preservative and cementing qualities of natural bituminous materials was an early discovery of ancient peoples and, because of these qualities, bitumens have been used in various applications since earliest times. Their introduction into roofing involves one of those amazing business success stories based on circumstance and opportunity where an impressive national enterprise grew from small, localized, and barely recorded beginnings. These beginnings were little more than 100 years ago.

In 1844, Samuel D. Warren is reputed to have started a roofing business in Cincinnati, Ohio, using paper and pine tar for covering almost flat roofs. To soften the pine tar he experimented with coal tar and later used only coal-tar pitch. In 1854, in Chicago, Samuel E. Barrett set up a roofing business that today is the Barrett Division of Allied Chemical Corporation. He had been selling pine tar and paper roofing for a short time before starting his own company. At this time, individual sheets of paper were immersed in the saturant, and the excess was scraped off by hand. Barrett switched to coal tar pitch exclusively and set up a continuous process of roofing-felt manufacture, using paper rolls 26 in. wide, and a laundry hand wringer to speed up production. Initially he purchased roofing materials from the pioneer Warren Chemical Manufacturing Company, which was an offshoot of the original Warren business. A little earlier America had taken rapidly to the idea of coal gas illumination, and gas plants producing gas from coal had sprung up near all the larger cities. The more gas that was produced, the more coal tar piled up in the gas plants. Gas companies were running into trouble with the municipal authorities concerning the disposal of the waste and the fouling of rivers and sewers with coal tar, and were having to employ haulers to dump the material. They were happy, therefore, to pay roofing companies such as Barrett's to dispose of the annoying problem.

The disastrous fire of 1871 in Chicago destroyed 17,430 buildings including the Barrett plant; damage amounted to $168 million. The post-fire rebuilding program created a tremendous market for building and roofing materials. The building industry was required to create a new city in an extremely short time. Economy in materials and labour was necessary, and most of the new buildings, which were of all types, had flat roofs. As a result of this catastrophic fire, built-up roofing from paper and coal-tar pitch and the Barrett business got a boost which assured their future. The Barrett company expanded its business across the country during the early 1900's, including Canada in 1906, and Allied Chemical was formed in 1920. The Barrett Division of Allied Chemical now produces a wide range of building materials and is a leading developer of chemical-based building products.

The foregoing might indicate that Barrett was the only roofer in the early days. This was far from the case, as it was not long before there was a large group of reputable roofers, and as usual a few irresponsible operators. By the early 1900's, the industry was considered to be in an unhealthy state because of questionable application methods and skimping of materials by some roofers. The Barrett company made an attempt to remedy this situation by introducing roofing specifications about 1906 and the system of bonding roofs in 1916. This was a forward step at the time and helped tremendously to standardize procedures and upgrade the quality of workmanship. The system itself had faults, however, and these forced the abandonment of the bonding system in Canada in 1960.

But this is the story of coal-tar pitch, which in many areas of Canada and the United States has been displaced entirely by asphalt. How did this come about? Coal-tar pitch built-up roofing was born of waste materials from the gas industry, and asphalt built-up roofing was born of waste materials from the petroleum industry. Neither science nor research played much part in the use of these materials and it is perhaps stretching a point to say that their use for roofing was an art.

Asphalt

Asphalt from naturally occurring seepages and deposits was being used for its preservative and cementing qualities three or four thousand years before Christ. A large source of natural asphalt, an asphalt lake, was discovered in Trinidad by Christopher Columbus and Sir Walter Raleigh. Both of them reported on this, after stopping there and caulking their ships with the material. The working of asphalt from natural sources, of which Trinidad Lake was the principal one, did not become commercially practical until the advent of the automobile in the latter half of the 19th century. The automobile needed smooth roads and asphalt was used for road paving. Native asphalt was very hard and needed a flux to soften it. The petroleum industry was having a problem disposing of the residue left from the distillation of petroleum. For many years enough oils were left in the residue to yield a fluid product which could be used as a flux for native asphalt, and most of it was disposed of in this manner and for laying dust on dirt roads.

Initially in the petroleum industry kerosene was the most important product, and the gasoline and heavy oils were difficult to dispose of. The rapid development of the automobile, however, changed the emphasis, and gasoline and lubricating oils became the important commodities. Kerosenes and heavy oils not suitable for lubricants had to be disposed of by the petroleum industry. Thermal cracking of kerosene to produce more gasoline relieved the situation with regard to kerosene-type materials, but increased the problems in regard to asphaltic materials, the supply of which was largely in excess of what was required for fluxing native asphalts and for laying dust on dirt roads. The refiners had to find other uses for the material, and of course public demand for better streets and highways led to its use in road building, eventually largely replacing natural asphalts. Applications other than road building were investigated and, with some alterations in manufacturing procedures, materials were produced for use in roofing and waterproofing applications. By the start of World War II satisfactory asphalts for road and airfield construction, and for the manufacture of roofing and roofs, was being produced by most refineries. Electricity had displaced gas for lighting, to a large extent for cooking, and to some extent in industry. New uses were also being found for coal and coal-tar in the new chemical industries. This natural change in emphasis on the use of material has continued and, since asphalt has some advantages over coal-tar pitch and is in more ample supply, the ratio of usage for roofing in Canada is currently about three or four to one in favour of asphalt.

Felts

What about the felts that form the basis of built-up roofing? As one might suspect, they too are a by-product - in this case of the paper industry - and utilize rags, wood bark and other wood waste, and scrap paper. Of course, rags were used in paper-making long before paper was used to make roofing felts. Today paper is manufactured mostly from wood pulp, and only a few companies in Canada and the U. S. still use rags in the manufacture of roofing felt, although the name "rag felt" is still commonly used to describe roofing felt. Rags were used principally because they made the felts easier to saturate and allowed them to absorb more saturant. The manufacture of saturated or saturated-and-coated roofing felt today is essentially the same operation as invented by Barrett, but carried out under fairly rigid factory controls.

Asbestos felts, consisting predominantly of asbestos fibres, were developed in the 1920's. It was claimed that they eliminated the potential deficiencies of moisture movement and decay found in organic fibre felt (rag felt) and improved the fire rating of the roof. Because of the small percentage of organic fibres necessary to facilitate satisfactory manufacture, asbestos felts are not entirely free from moisture movement and decay and, principally because of higher cost, have not been widely used in Canada. In recent years glass fibre felts have been introduced into built-up roofing. These are almost entirely free of dimensional changes from moisture absorption and, of course, are completely free of decay. Because of tensile strengths and brittleness characteristics, the significance of which is not yet fully appreciated, they too have not been completely trouble-free, despite the high hopes for their performance.

Construction Industry Today

What has happened to building during the hundred years or so that built-up roofing has been struggling to become a craft? Looking around any of the large Canadian cities, one can see hundreds of public, commercial, and industrial buildings recently completed or in construction. Most are of spectacularly modern appearance. Although the curtain wall tends to give them all a sameness, one must admit that building has greatly changed in recent years, and in architecture there are new building types, new problems, and new clients. An abundance of work has resulted in the western world as a result of an expanding economy and an expanding population. Architects and contractors have been very busy and almost certainly will continue to be so. There is no compulsion, therefore, for them to give special attention to any one aspect of building such as roofing, and this was particularly true when bonding of roofs was the practice.

Most of the elegant new buildings are protected from summer sun and winter storm by a roof surface that is essentially the same as the covering developed a century ago from waste products, to relieve the roof construction problems of the fire-devastated city of Chicago. It is reasonable to assume that many of the more recent failures in built-up roofing are due to recent changes in the practice of building, which have not been taken into account in roofing design and application. These changes are many and varied, and are described later in this paper.

Roofing today is of a composite construction and one thing about which very little is known is the interaction between the structural framework and the roof decking, or between the decking and the insulation and roof covering laid on it. It is known that roof structure movement is important in relation to continuous membranes, but the rate and amount of structural movement in actual buildings is difficult to forecast. Even if these could be forecast, there is very little information available on the engineering properties of built-up roofing membranes, which would enable designing to allow for movements. Most current laboratory investigations, including those at the Division of Building Research, are only involved with the components and it is difficult to relate their isolated behaviour to the behaviour in composite construction. In roofing, perhaps more than in any other industry, there appears to be a great deal of off-the-cuff opinion, unsupported by knowledge or research, with half-truths the rule rather than the exception. Research organizations around the world are devoting some energy to these problems, and the situation is gradually being remedied.

The Roofer Today

What can the roofers do in the midst of all this? There is very little they can do about the innovations in building practice that have caused some of the problems, and there is very little they can do in the area of research. There are areas, however, in which roofers can improve the industry. Roofers have already taken long strides in the right direction with the formation of roofing associations such as the Canadian Roofing Contractors Association and the Alberta Roofing Contractors Association. Dignity and respect, which the members seek, are synonymous with pride of workmanship on work properly carried out. Roofers, therefore, have a job to do in training roofing personnel in properly defining standards of application and workmanship. The publication of the CRCA Specifications Manual is an indication of the serious intent by roofers to ensure that roofing is adequately specified by architects and engineers. Many roofers realize, however, that this is not enough. Roofers can do a great service to the Canadian construction industry by defining good roofing practice so that manufacturers, architects, engineers, contractors, and roofers could all be working to common standards. At present even the terms used in the roofing industry often have different meanings to the various people involved with roofing.

The Committee on Asphalt and Tar Roofing Materials of the Canadian Standards Association is working on a Code of Practice to cover design and application of built-up roofing. The support of the Roofers' Associations is necessary, particularly in relation to application, and to assure that this work is pushed forward by the Committee. The Code of Practice could form the basis for part of an educational program for roofers, which roofers realize is badly needed. Craftsmanship has been defined as "the quality imparted to anything in the process of making," and a craftsman as "one who practices a handicraft." By these definitions there are few craftsmen in the roofing industry. Even roofing foremen often do not understand or appreciate why certain procedures are necessary in roofing application. How many, for instance, know the function of gravel surfacing? Experience indicates that very few appreciate such matters. The casual labour employed on most jobs know nothing of the trade. Good workmanship can usually only be obtained through the art and skill of workmen or craftsmen, and if they do not have the art and skill, satisfactory application is unlikely to occur even by chance. It would appear that this is the reason the asphalt roofer does not enjoy the respect given to some of the longer established roofing trades, such as the slater and thatcher in other countries. Roofing associations are very concerned about an educational program for the roofing personnel of the member firms, and steps are being taken to implement such training.

Architects and other designers receive a great deal of criticism in connection with inadequate roofing design and specifications, much of it deserved. Those in the roofing industry, however, surely cannot expect the architect to be an expert roofer. The members of roofing associations, and their roofing personnel, must be the application experts, the craftsmen. Roofers have to be competent and responsible in solving job problems, advising on the correct solutions to remedy undesirable conditions, to assure a first-class job. The asphalt roofer's trade has allowed itself to be greatly influenced by manufacturers, architects, and contractors. Roofers should be the ones to determine, in consultation and co-operation with the others, of course, when the conditions on a job are suitable for roofing. Most roofers have been involved with jobs where the architect or contractor, or both, have insisted on roofing when the roofer was aware that conditions were not suitable. It would be wonderful to be in a position to refuse when such a situation occurs. It would be naive to suggest that this is always or even occasionally possible. It is important, however, that roofers be more emphatic through their associations in pointing out to architects and contractors the dangers of roofing under unsuitable conditions. Confidence in roofers from designers will only come from honest and straightforward dealings and co-operation over a period of time. Roofers have to be sure of what they are doing and actively make this knowledge known.

THE ARCHITECT

Criticism of Architects

It is a current fad for everyone, including architects, to criticize architects as a group for their failings of one sort or another. The criticism to which the profession is subjected from architects appears to indicate an insecurity and a fear of the future that exists within the profession, but there is no doubt that this self-appraisal is a good sign. Architects, as perhaps never before, are questioning the system of architectural education and many other previously accepted standards of the profession, and are becoming increasingly concerned about the public image of the architect. Despite the conviction of architects that they are the leaders of the construction industry, a conviction not necessarily shared by others in the construction industry, architects at the moment are often considered to be a "necessary evil." What the profession clearly has to guard against is being considered an "unnecessary evil." It is quite conceivable that the construction industry could exist without professional architects, but impossible for architects to exist without a construction industry.

The architect's lot is not an easy one, even if one discounts the frustrations attendant on being an adjudicator, financial adviser, decorating consultant, and guardian of culture and aesthetics. The design and construction of a building involves the combination of a variety of materials. Every architectural office is bulging with quantities of trade literature, and often perhaps even stacks of research reports, that describe the virtues and confirm the properties of the many materials available for use. To the average layman or a naive architect, designing a building merely means choosing aesthetically-pleasing materials and fitting them together.

Most architects, of course, know that this approach is quite ridiculous, and are aware that materials which have most desirable properties in themselves can become unmanageable monsters when combined with other seemingly excellent materials to function as building elements. And yet, early and serious malfunction and deterioration of some of our buildings indicates a lack of appreciation of many of these factors. These factors involve the unchanging laws of physics and chemistry, and their effects on some of our complex assemblies of building materials - in other words, basic building science. Vapour pressure, moisture migration, air and heat flow, light and sound transmission, volumetric change and electrolitic action are not mysterious phenomena of interest only to engineers and scientists. These are some of the mechanisms that daily affect the combinations of materials that go to make up our modern buildings.

A criticism of the profession of architecture is that it merely pays lip service to science and research. Architectural students are not taught basic building science, and such engineering courses as are given are usually considered as something additional to architectural design, rather than a part of it. Practicing architects, although generally aware of the science phenomena mentioned, find the effort too great under the stress of day-to-day problems to become skilled in the application of these phenomena to architectural design. There is a tendency to think of any particular material or system as being good or bad, depending on the architect's experience with its performance on an actual building. This approach assumes that durability is a fundamental property of the material or system. Nothing could be further from the truth. The performance of a material or system depends on the environment to which it is exposed and the degrading effects of service. A proper understanding of building science helps one to recognize the pertinent factors affecting the performance. It is then possible to analyze designs systematically as to the probable performance, and choose materials or systems to satisfy the varied requirements. As well as remaining the guardian of culture and aesthetics, the architect must reassert himself as a technical leader, and to do this he must know more about nature's laws with which he can generally cope, but which he cannot change and is ill-advised to flout.

Architects have been blamed for building problems in many specific areas within the building industry. In connection with roofing, for instance, inadequate design and specification, as well as lack of supervision, is usually attributed to the architect. Certainly a lack of concern for design detail and the supervision of workmanship were encouraged by the system of bonding roofs that existed in Canada from 1916 to 1960. Under the conditions of present architectural practice, it is ridiculous to suggest that the architect should be an expert roofer, an expert carpenter, or an expert in any trade. For every trade, however, the architect is required to have knowledge of the materials used, and the factors that affect their performance. It is also extremely important for the architect to recognize new factors brought about by changes in building practice.

Changes in Building Practice Related to Roofing

It appears that many of the more recent roofing failures may be due to changes that have recently taken place in building practice, which have not been taken into account in roofing design and application. There has been an increasing use of dead-level roof decks, and consequently poorly drained roof surfaces. Precast concrete and many other types of multiple unit roof decks are now widely accepted. Deflections of such decks have not been investigated in relation to the effect on roofing. The obvious effect of permanent deflection from creep on roofs intended to be flat is the ponding of water which increases the failure hazard. Greater thicknesses of lighter insulations placed on top of roof decks have been used to achieve better thermal resistance, but they provide a soft underbedding for the roofing membrane and subject it to greater variations in temperature. The increasing use of vapour barriers, while restricting the entry of moisture into the construction, introduces new problems caused by moisture that may be trapped in the construction. Air-conditioning and humidification of many building types are common, and these measures aggravate the problems of moisture transfer into the building components. Year-round construction has added to the hazard of trapped construction moisture in building materials and systems. This is particularly true in relation to roofing, where no protective cover is used, such as is employed on some other phases of building construction. Apart from the hazards of rain, snow, and ice on roof decks, and the possibility of wet materials from improper storage, there is great danger of inadequate adhesion of felts due to application of materials to cold and wet surfaces, or due to overheating materials to counteract the cold. The overheating may also destroy the desirable properties of the bitumen. In some buildings large quantities of moisture are released into the closed-in building from wet-finishing operations, such as concreting or plastering. Under certain conditions, such moisture can penetrate into the roofing system and cause subsequent deterioration.

DESIGN CONSIDERATIONS - ROOFING SYSTEMS

In the design of a roofing system, the most important consideration is the provision of a watertight or water-shedding covering to keep the interior of the building dry. Steeply-pitched roofs shed water rapidly and a covering of overlapping impervious units can be used to achieve this. Flat and low-pitched roofs tend to hold water, or shed it very slowly. The covering, therefore, must be jointless and watertight.

This appears to be very difficult to achieve because of the nature of the materials usually used. Organic felts, most commonly used in the built-up bituminous roofing systems, can absorb moisture with consequent dimensional changes and deterioration. Bitumens oxidize from exposure to air, moisture, heat and ultraviolet light, and the oxidation products are water-soluble and volatile. They become very brittle when exposed to low temperatures, are subject to slumping at high service temperatures, and are subject to deterioration at temperatures only slightly above those required for application. The quality of the finished roofing depends largely on the workmanship and the weather conditions during application.

Building Movement

Factors such as roof structure movement, which may be unimportant on a steep shingled roof, must be carefully considered in relation to a continuous membrane. It may be necessary to provide suitable waterproofed discontinuities in the membrane at places where there may be movements greater than the membrane can accommodate. Of course, it may also be necessary to consider the design of the structure to reduce the amount of movement as much as possible. The rate and amount of structural movement is difficult to forecast for an actual building. In addition, there is little information available on the engineering properties of built-up roofing membranes, which have not in the past been considered as load-bearing. The strength of the actual membrane depends a great deal on workmanship, and very little is known about the behaviour of membranes due to temperature and moisture changes. The membrane must, of course, be considered in relation to roof insulation, vapour control, and heat and vapour ventilation of the roof system. For these reasons it is difficult to provide positive recommendations for practical roof deck and roof membrane design.

It appears certain that a built-up bituminous felt roofing membrane should not be laid so that it is solidly adhered to two parts of a building which move in relation to each other, even if the movement is very small. This condition occurs wherever a roof deck meets a vertical surface at a parapet, curb, penthouse, or wall. The standard procedure in this condition is to provide a 45-degree cant strip with the roofing felts carried to the top of the strip. Base flashings are then applied to the wall extending out onto the deck over the roofing membrane. There is seldom any attempt made to allow for movement. Such allowance is generally necessary and can be provided easily with the use of a separate wood skirting attached to the deck. Cover flashings must be installed at the same time as the roofing to prevent water penetrating behind the skirting.

Such a condition also occurs with precast roof deck elements at each joint between elements. With small units this does not seem to cause many roofing problems, but with larger units trouble will probably occur unless adequate provision is made for movement. Tests by the Division of Building Research indicate that roofing membranes fail at a strain of approximately one per cent at -20°F. To avoid fracture of the membrane at structural joints it therefore appears necessary to separate the membrane from the roof deck at the joint for a sufficient width to reduce the strain to a value of less than one per cent. Knowing the amount of possible movement at a structural joint, it is a simple matter to calculate the free width of material necessary to achieve this. A strip of material laid over the joint will then prevent adhesion of the membrane to the deck for the width required.

It is usual in building design to provide an expansion joint in the roofing only where expansion joints are provided in the structure, as required where there is a change in direction of framing, where wings project from a main structure, or on any relatively long or large section of a building or for some other structural reason. In most modern buildings the roof and walls are insulated outside the structural frame, and after the building has been constructed and is in operation the frame will usually be subjected to very small temperature differentials. The structural engineer on this basis may be justified in making relatively large spacings between expansion joints. If construction is done in cold weather, the effect of rapid warm-up when the building is closed in must also be carefully considered. The spacings determined from structural considerations alone may not be adequate for the roofing membrane. It will be subjected to the full range of outside temperatures, and for black surfaces over insulation the range may be increased by at least 100 F degrees in excess of the range of ambient air temperatures. Seasonal temperature differentials of 200 F degrees and temperature variations of up to 80 F degrees in a few hours are possible in many parts of Canada. The coefficient of expansion of bituminous membranes is such that these temperature variations, particularly at temperatures below 30°F, will tend to cause quite large movements. There is very little knowledge about the manner in which such movements are resisted or accommodated by the roofing system. It can only be suggested at this time that limiting the extent of continuous bituminous membranes to 100 to 150 ft appears to be of some help in reducing the incidence of membrane splitting.

Insulation of Roofs

Roofs can be insulated in four ways (Figure 1):

1. Above the structural deck (this is usual practice with rigid insulation on wood, concrete or steel)

2. By the use of an insulating material to form the deck itself (aerated lightweight concrete or fibre)

3. Immediately beneath the structural deck (poured gypsum or other lightweight material over formboard)

4. On a ceiling below the roof proper, with a loft or attic between the ceiling and the deck (this is standard practice in house construction, and in some industrial buildings).

It is important to be aware of the differences between these methods, and that each involves special problems. Knowing these differences, it is usually possible to design a roof construction that will give the best performance at the least initial and operating cost for the local climate, and for the anticipated occupancy of the building. The lowest initial cost for insulation and the lowest operating cost for heating and cooling can be attained better with an insulated ceiling below a ventilated loft space, than with insulation either above, in, or immediately below the deck. This design also has comfort advantages and can be designed to handle occupancies in which very high moisture conditions prevail.

Many of the roof systems in which the insulating material forms the deck, or where insulation is placed directly below the deck, are entirely unsuitable for buildings with a high indoor moisture content. When the roof is to serve as an interior ceiling, the choice between insulating above, within, or immediately below the deck will be determined by anticipated interior moisture conditions, internal appearance, and relative cost. If the roof is to carry traffic loads the insulation above the deck must be a load-bearing type, but it seems more logical to consider the use of a more efficient non-load-bearing insulation below the deck or on a ceiling forming a loft space.

In all cases careful attention must be given to vapour barriers and their location, or to vapour control by ventilation, wherever the moisture level generated by the occupancy during periods of cold weather indicates a potential condensation problem.

The most usual roof construction used in Canada is the one where insulation is placed directly above a structural deck, and a vapour barrier is placed directly on the deck. The insulation used, although usually rigid and with some load-bearing characteristics, is generally porous. Most insulating materials are largely air-entrapped by cells or fibres, and the air content in some insulations may range from 50 to 95 per cent of the mass. In addition, some moisture may be present. Considerable moisture may enter the insulation due to inadequate storage protection or inclement weather during construction. If material in this condition is confined between a tight roofing above and a tight air and vapour barrier below with all edges sealed, pressures that built up within the system from solar heating on the roof surface will certainly cause blistering, and the better the roofing membrane the more likely it is to blister. That many such roofs have performed reasonably well indicates construction is not tight and the air does escape. If air can escape to the inside of the building, a breathing or pumping action may take place. For buildings with a high moisture level occupancy, such breathing action could saturate the insulation with moisture over a period of time. Wet insulation has less heat resistance and so will aggravate the problem and, of course, organic insulations, if wet, will rot in time and fail completely. It appears that a properly designed roofing of this type must make provision for the insulation to breathe to the outer air, where the vapour pressure is the lowest.

Condensation of Water Vapour

If water vapour can penetrate into the roof construction in winter from within the building it will condense on the underside of the cold roofing. This is inevitable unless the vapour pressures inside are equal to those outside. No dripping will occur until absorptive insulation and other absorptive material of the construction are fully saturated. To prevent this, a vapour barrier may be installed as near as practicable to the warm side of the construction. Condensation can be completely forestalled if this vapour barrier is maintained at a temperature above the dewpoint of the indoor air. It is important to understand that the over-all heat resistance (U value) of the roof is not the important factor, and, in fact, a type of deck that is a poor insulator requires less insulation to prevent condensation than does a good insulator when the vapour barrier is placed above the deck.

Consider an example in Ottawa of a steel deck and a 3-in. plank deck (Figure 2). Assume indoor air will be kept at 70°F and the relative humidity (RH) at 50 per cent. Using the winter design temperature of +10°F for outside air, how much insulation is required to prevent condensation at the vapour barrier?

The dewpoint temperature for 70°F air at 50 per cent RH is 50°F, and therefore the vapour barrier will have to remain above 50°F if condensation is to be avoided.

The line A to F in Figure 2 indicates a rate of heat loss which must not be exceeded if condensation is to be avoided for the steel roof deck. This rate projected on a resistance scale graph of temperature gradients indicates that the total resistance required of the construction is 1.8. Since the construction without insulation provides 1.11, only 0.69 is required from the insulation, and this can be provided by 0.69/2.78 = 0.25 in., that is, 1/4 in.

Line AB in the diagram indicates a rate of heat loss which must not be exceeded if condensation is to be avoided for the wood deck. The rate of heat loss is considerably slower because of the resistance of the wood deck. When AB is projected to C it can be seen that the total resistance required is 11.7 and, since the construction provides 4.39, the insulation will be required to contribute 7.31 and this will require 7.31/2.78 = 2.63, or approximately $2\frac{3}{4}$ in. of insulation.

The U value for the insulated wood deck would be 0.08 and for the steel deck it would be 0.56. Obviously more insulation would be used on the steel deck than 1/4 in. for reasons other than condensation.

Suppose the insulation used on the wood deck were 1 in. Total R would be 4.39 + 2.78 = 7.17, and the temperature gradient through the deck would be along line DEA, with the temperature at the vapour barrier 38°F. The room could support 30 per cent RH under these conditions. If 1 in. of insulation were used on the steel deck, total R would be 1.11 + 2.78 = 3.89, and the temperature gradient would be along line HJA with temperature at the vapour barrier of 60°F. The room under these conditions could support a relative humidity of 70 per cent.

DESIGN CONSIDERATIONS - BITUMINOUS ROOF COATINGS

Choice of Materials for Bituminous Roofing

The properties of the materials used for built-up roofing are seldom understood by designers or roofers. The important properties required of bitumens are impermeability to moisture, good adhesive and cohesive properties, and an ability to deform slowly and continuously when subjected to shearing forces. The bituminous materials chosen for roofing have these properties to a greater or lesser degree. Despite a good deal of research in recent years, there still remains a considerable lack of knowledge of the behaviour of bitumens over wide temperature ranges. Although certain standards have been established through co-operative research of the petroleum and roofing industries, and form the basis of ASTM and CSA material specifications, it is still doubtful if the empirical tests involved are adequate to define properly the best materials for use in terms of end use and durability.

Bitumen is a generic name applied to mixtures of predominantly hydrocarbons. In Canada and the United States, the term is loosely used to describe either coal-tar pitch or asphalt. Coal-tar pitches are produced as a by-product of the destructive distillation of bituminous coals in the manufacture of gas or coke. Asphalts result from the natural or industrial distillation of petroleum. Natural asphalts are rarely used for roofing in this country but, from the confusing array of petroleum asphalts, two types are mainly used. Residual or straight-run asphalt, which is the residue after the removal of gasolines, oils, and other volatile products from crude oil, is often used directly or with slight air oxidation. Blown asphalts are harder asphalts produced from the same residues and strongly air-oxidized.

Two of the empirical tests used to describe the properties of bitumen are penetration and softening point. Penetration gives a measure of brittleness; softening point gives a measure of flow under controlled conditions.

The temperature interval between the softening point and the point at which a brittle condition is reached gives a measure of the temperature susceptibility of the material. This can vary a great deal, depending on the crude oil source and the bitumen processing. Successful use of bitumen can usually be assured when the limits of temperature, defined by its brittle condition and softening point, are not exceeded in service.

The desirable properties of the bitumen are water resistance, weather resistance, chemical and physical stability, low sensitivity to temperature, high flash point, low vapour formation, and compatibility with other bitumens used in roofing. The roof slope determines the degree of water tightness necessary. Water absorption and penetration are a function of time, and bitumens used for roofings on steep slopes where the water runs off quickly need not be so resistant to water as bitumens for flat roofs. This is why it is possible to compromise in regard to water resistance, in order to have a bitumen that does not soften and flow off steeply sloped roofs. Blown bitumens, which are air-oxidized to give them higher softening points and less susceptibility to temperature, are slightly inferior to low softening-point residual bitumens in regard to other properties such as water resistance. When heated to working temperatures the bitumen should have the least possible volatile content, be free of any tendency to coke, or any tendency for separation of oily components in working or during weathering. A high flash point is necessary to diminish the risk of fire not only during application, but also to the completed roof. Compatibility of saturants with coatings, and of coatings with the bitumen used as the adhesive between plies of felt, is very important. Incompatibility can cause the breakdown of the desirable properties of one or both of the bitumens involved and result in a lack of cohesion and adhesion and of water-tightness. The architectural designer does not generally have a choice regarding the saturant or coating in the manufacture of felts, but will normally have some choice as to the type of bitumen and felt used in the construction of built-up roofing. There are three types of asphalt available in Canada for hot-applied bituminous roofs. The Canadian Standards Association has set the requirements on these as shown in Table I.

TABLE I

Type of Bitumen	Use	Softening Point, deg F	Pene-tration, 1/10 mm	Flash Point, deg F	Ductil-ity, cm
Asphalt Type 1	Flat to inclines of 1 in. to 1 ft	140/150	25 - 40	450	10
Asphalt Type 2	For inclines 1 in. to 3 in. to 1 ft	165/175	20 - 30	450	3
Asphalt Type 3	For inclines over 3 in. to 1 ft	190/205	15 - 25	450	Not speci-fied

Other properties are also specified, but those given in Table I are of most use to the designer.

In weathering tests carried out by the Division of Building Research on Type 3 asphalts, the only property that appeared to have a correlation with durability was ductility. This is a small quantity for Type 3 asphalts and difficult to measure accurately in most industrial laboratories, when the test equipment becomes worn from constant use. Ductility is measured by the distance to which the bitumen will elongate before breaking when two ends of a briquet specimen are pulled apart at a specified speed and at a specified temperature; 77°F and 5 cm per min are the normal conditions.

Coal-tar pitch is also still used in Canada for hot-applied bituminous roofing. For coal-tar pitch the requirements and methods of test specified by C.S.A. are slightly different than for asphalt. Penetration is not specified, but for roofing pitch softening point is 140/155°F and ductility 50. The usual range for softening point is 140/150°F with an allowance for 145/155°F for use in hot summer weather. Coal-tar pitch can only be used on flat or low-sloped roofs (up to perhaps 1 in. to 1 ft), and it is usually considered that it must be protected by gravel or slag.

Three types of felt classified according to the raw fabrics are commonly used in Canada. The raw fabrics consist of felted organic wood fibres, inorganic asbestos fibres, or a mesh of glass fibres. They are impregnated or saturated by passing them through a bath of hot bitumen. This is done to displace air and moisture from the voids of the fabric, and to give added durability so that the finished felts can be transported and applied with greater ease. Saturated felts are usually used in the construction of hot-process built-up roofing. For certain hot applications and for most cold application roofing, saturated organic fibre and asbestos fibre felts are factory-coated with hard asphalt to which mineral fillers have been added, and are referred to as asphalt-coated felts.

Organic fibre felts, which are essentially waste paper and wood pulp, and sometimes a small percentage of rag fibre, have certain inherent faults despite their widespread use. It has been difficult to evaluate the inferior properties in terms of performance on roofs, but it is generally believed that many roofing problems stem from weaknesses in the base fabric. When immersed in water, coal-tar pitch saturated felt (tar felt) will pick up 80 per cent moisture by weight, and asphalt saturated felt, 50 per cent moisture by weight. These changes in moisture content cause relatively large dimensional movements and the presence of moisture causes rotting of the organic fibres. This is why it is so necessary to assure that roofing felts do not become wet during storage or application.

Asbestos felts, consisting predominantly of asbestos fibres, but including a small percentage of organic fibres necessary to facilitate satisfactory manufacture, are also not entirely free from moisture movement and decay.

Glass fibre felts which are only slightly affected by moisture would appear to be a logical choice for built-up roofing. Applications of these felts, however, have been particularly plagued by so-called thermal splitting. This type of splitting has occurred with all types of felts, and with rag felts this is frequently combined with other types of deterioration.

Some current thinking favours the use of coated roofing felts instead of saturated felts. These have been used for some years in cold process applications, and for hot applications in some countries, notably Australia. This largely eliminates the hazards of storage and construction in relation to the felts, but may introduce other problems. The weights of coated felts now available might be very difficult to work with in cool or cold weather, and adhesion might be adversely affected by sand or other mineral dust surfacing used to prevent sticking in the roll, or by incompatibility of bonding bitumen and coating bitumen. Coal-tar pitch and asphalt are definitely considered incompatible, and for this reason it is advisable to avoid contact of the two bitumens, using asphalt with asphalt-saturated felt, and coal-tar pitch with tar-saturated felt. Coated felts are considered necessary for use as a base sheet over any deck where only partial bonding is anticipated, such as over preformed elements of a multi-unit type deck. In this application a saturated felt is subject to moisture pick-up and subsequent deterioration. Also, a coated sheet is desirable for the top ply of the roofing membrane. This will protect the underlying membrane against moisture from sudden showers, and will provide better long-term protection against penetration of moisture into the membrane from water on the roof.

Drainage

Although the majority of roofs in Canada are built to be entirely flat, this is seldom a necessity and is seldom achieved because of construction inaccuracies and normal structural deflections (Figures 3 and 4). This produces a double weathering hazard. Water remaining in pools on the roof has time to penetrate and further deteriorate any imperfections in the membrane, and at the edges of pools the combined attack of water and sunshine is likely to break down and deteriorate the surface very rapidly. Ice action, from freezing of ponded water, is believed to be an additional hazard. It does not appear that such ice can split the roofing membrane, but local damage from water that penetrates existing cracks, wrinkles and holes or other defects may be considerable. A roof that is well drained will usually give fewer problems than a flat poorly-drained roof.

It is often argued that the provision of proper slopes to drains is too costly, since the structure has to be sloped or a fill provided to make the slopes. If one compares the cost of insulated walls and the cost of roofs, it appears obvious that this is not a valid argument. The roof performs a similar function to the wall - separating the indoor and outdoor environments - and often, in addition, protects the walls from water penetration. Insulated walls in modern buildings, not including the structure, often cost anywhere from $4.00 to $16.00 psf; roofs, including the deck but not the supporting structure, seldom cost more than $2.00 psf. It would appear that, even if improvements doubled the cost of the roof, it might be easily justified on a functional basis. Many architects require no justification except some dubious aesthetic rationalization for subjecting clients to additional cost for structures and peculiar roof shapes that represent gross misuse of our engineering technology.

Roof Temperatures and Surface Treatments

Roof insulation provides many advantages in roof design, but generally imposes more severe conditions on a bituminous membrane than if it were not used. The membrane is subjected to solar heating and emissive cooling, and the temperature differences over an insulated roof are much greater than for a non-insulated roof.

Black-surface temperatures on insulated roofing panels have been measured as high as 165°F by the Division of Building Research, and calculations indicate that temperatures of roofs may be considerably higher than this due to solar radiation. Emissive cooling, which will occur on clear nights, is the reradiation of energy from the roof surface to the sky. This heat loss from the roof surface to the sky will result in cooling of the roof surface below the ambient air temperature. This may amount to 15 F degrees below ambient. The seasonal range of temperature variation to which roofing membranes may be subjected appears, therefore, to be 200 F degrees almost anywhere in Canada, and considerably more in some locations. Considered of even greater importance are the rapid fluctuations that can take place with changing weather conditions, both in summer and winter. It may not be too important that a summer rain can change the roof temperature by 80 F degrees in half an hour, because at this temperature range the coefficient of expansion of the material is very small. During the winter, however, with a rapid freeze from thawing conditions, the membrane may be subjected to a temperature change from 50 to 100 F degrees in a few hours in the temperature range where the material behaves as a brittle elastic solid with a large coefficient of contraction.

The high temperatures reached at the surface are also a definite factor in the oxidation deterioration of bitumen. The maximum surface temperatures, the range of temperatures, and the fluctuations can be greatly reduced by the application of proper surface treatment. With an ambient air temperature of 85°F, a black asphalt roof over an insulated deck would have a maximum surface temperature of about 165°F, or 80 F degrees above ambient. Crushed stone would reduce the surface temperature to about 150°F, or 65 F degrees above ambient. For white marble chips the temperature would be approximately 120°F, 35 F degrees above ambient. White paint and plastic coatings would reduce the temperature in some instances below 100°F to keep the surface temperature only 10 to 15 F degrees above ambient. These figures merely give an indication of the order of the effect of insulation and surface treatment.

A comparatively thin layer of bitumen, as used to form the final waterproofing coating of a built-up roofing membrane, does not give adequate waterproofing or wearing qualities, and some additional protection is necessary to obtain a satisfactory roofing. A possible exception to this is the clay-stabilized asphalt emulsion, but the weathering qualities of this material are also much improved by a surface treatment in the form of an applied coating. Since the finished layer is the first line of defence against moisture penetration and deterioration, it must be applied exceptionally well. More bitumen is used for the top layer than between plies, and this must be continuous and give complete coverage. The purpose of a surface treatment is to reduce photo-oxidation of the bitumen by shielding it from direct sunlight and air, and also to reduce the excessive temperatures that can occur on black surfaces, and that tend to accelerate the oxidation process. The most usual surface treatment for hot-process roofs is a coarse mineral-aggregate dressing of gravel or slag (Figure 6). The gravel also helps, to some extent, to prevent flow of the bitumen in hot weather. Surface dressing of this type will only perform its intended function if the material is opaque to ultraviolet light, is of correct size and grading, and is applied in sufficient quantity to give complete coverage. This complete coverage must be maintained if satisfactory service is expected (Figure 7).

Attention to details of finishing, both in design and application, is extremely important. Detailing should be such that finishing can be completed as the work proceeds. When areas of a roof have to be left unfinished, with felts exposed to the weather, deterioration can take place which will ruin the roofing before the work is completed (Figures 8, 9, 10).

Flashings

In the construction of a built-up roofing membrane, an attempt is made to provide a continuous uniform membrane, which is turned up at vertical surfaces where walls or other items extend above the general level of the roof. The membrane is intended to hold water while it drains slowly to the drainage outlets. The turned-up portion of the membrane at vertical surfaces, and watershedding devices where the turned-up portions terminate, are referred to as flashings. A very large proportion of leaks in bituminous roofs in this country occur at flashings, which are frequently weak points in the roofing system.

Through-wall flashings for parapet walls, structural penetrations through the roof for support of other equipment, and expansion joints are additional details that must be considered carefully by the designer. Details of the treatment for such items should not be left to the roofing applicator.

Application of Materials

It is necessary to liquefy the bitumen for use to form thin continuous films, and to secure proper adhesion to solid surfaces. This may be done by heating, by dissolving in organic solvents to give solutions, or by emulsifying in water. The first method is usual for hot-process roofing, and curing takes place by cooling to the service temperature range. Solvent solutions, which are called cut-backs, are used cold as primers and adhesives, and cure by the evaporation of the solvents. The solid asphalt remaining is exactly similar to cooled asphalt of the hot process. Concentrated solutions are made into pastes with the addition of fibrous inorganic mineral fillers, which gives them a trowelling consistency; they are generally called mastics or plastic asphalt cements.

Emulsions, which are very small droplets of bitumen in water, are stabilized by the addition of a filler with small plate-like particles which orient at the interfaces between bitumen droplets and water. A bentonite clay stabilizer is usual for roofing emulsions. Curing takes place by the evaporation of the water, and the clay particles form a network throughout the remaining film. This gives excellent stability to the mass and the resulting cured material has more desirable characteristics than solid asphalt.

The waterproofing property of a bituminous membrane depends on the existence of continuous films of bitumen. This is achieved by building up a membrane with alternate layers of bitumen and felt. The felt imparts strength to the membrane, and stabilizes and prevents the flow of the bituminous waterproofing films. In the case of roll roofing and shingles, the felt forms the base that allows the manufacture and transport of prefabricated bituminous films.

The method used in Canada for laying a roofing membrane is one that might be described as a shingle method (Figure 5). All the layers for an area of roof can be applied concurrently; the size of the side overlap determines the number of layers or plies of roofing. The method is simple, convenient, and fast. Any lifting at the laps or wrinkling of a felt layer, however, tends to provide a direct path for water or moisture to the insulation or deck to which the membrane is applied. Separate layers, or at least some break in the shingle laying, such as two and two in the case of four-ply roofing, would obviate this disadvantage. The work must be planned for continuous coverage, with all layers laid at the same time. The practice of laying two layers over the complete roof, with additional layers applied at a later time, is very hazardous as there is danger of trapping construction moisture between the layers, and in some cases adhesion between the layers may be poor. When the shingle method of laying is used, it is very important that felts be applied smoothly without wrinkles and that the side laps be properly and entirely stuck down. This can only be achieved by careful workmanship and brooming-in of felts.

Summary of Factors that Usually Assure Satisfactory Roofing

A few of the more important factors involved in the design and application of trouble-free bituminous built-up roofing have been described. There are a great many specification details that have not been mentioned. Bearing in mind what has been said, a summary of factors that usually assure successful bituminous roofing include the following:

Design

1. Roofs must be sloped to drain water.

2. Precautions should be taken to keep movements of the underlying structure to a minimum, and allowance made for anticipated residual movements.

3. Materials and systems must be chosen that are appropriate to the requirements of the specific building. This involves vapour barriers, insulation, and coated base felts.

4. Penetrating the roof membrane with vents, ducts, and other mechanical equipment should be avoided, whenever a practical way can be found to do otherwise. Flashings at walls and roof penetrations are vulnerable points and need care in design (Figures 11 and 12).

5. A surfacing material that will limit roof-surface temperatures and temperature fluctuations is essential.

Application

6. The surface of the roof deck must be dry prior to the application of insulation or built-up roofing.

7. No insulation or roofing should be installed during inclement weather, when any precipitation whatever is present.

8. Storage and protection must be provided to ensure that insulation and felts do not pick up moisture prior to installation in the roof system.

9. All plies of felt should be solidly adhered without voids or air spaces between plies. This requires accurate temperature control of bitumen and brooming-down of felts.

10. Care is required in the execution of flashing details if water penetration is to be avoided at such vulnerable places.

Maintenance

11. To avoid costly repair or early replacement, regular inspection and preventative maintenance are required, and the owner must be aware of this.

The above summary is not necessarily exhaustive, and many of the items shown could be further amplified. What appears to be required is a manual for roofing design and application.

Roofing is one area of building construction and maintenance where interest in the building roof varies with the seasons. During the summer, bituminous roofing tends to seal itself to some extent and even during heavy rains it is unlikely to leak. After the rigors of winter, however, leaks show up during the first thaw and all through spring when pools of water lying on the roof are fed from melting snow and ice. If water lies on the roof for long periods of time it will find its way through even minor weaknesses in the surface. Usually, by the time the roof dries off sufficiently to make repairs, the leaking has stopped, and owner, architect, and roofer stop worrying until the following winter brings on leaking again.

When a roof leaks the architect is usually blamed and, if one believes what the roofers and manufacturers usually say, the architect is responsible for a large number of troublesome roofs. The problem of achieving trouble-free roofs has been used as an example to show how neglect of the factors involved in design and application of roofs can result in criticism of the profession of architecture. Conscientious design and supervision of work would eliminate much of such criticism. A great deal of attention is being given at present to the problems of roof systems by various agencies in Canada and elsewhere. The results of such study and research will aid the architect in avoiding some of the difficulties experienced in the past.

THE DIVISION OF BUILDING RESEARCH

The work of the Division of Building Research involves a constant search for information in connection with materials and their properties, as affected by the forces to which they are subjected in service. It further involves, of course, the provision of such information as is available from research to those who need it in design work in relation to construction problems. The work of the Division is divided into two area of work - Building Science and Building Practice - and the work in each area is carried out by a number of sections. Building Science is the term used to describe the work of eight sections whose main concern is laboratory work. In Building Practice there are five sections whose work may be described as assisting in the application of research results in the practice of building. In Building Science the sections are involved with problems of foundations, structures, materials and the effects of fire, sound, air, heat and moisture. The Sections of Construction, Housing, Building Standards, Publications and Library, which constitute Building Practice, tend to deal with building problems as they relate to the whole structure, and they act as the two-way street between research and the construction industry, with information traffic flowing in both directions.

At this time the Division has two research officers who are spending almost full time on roofing, and additional work has started at the Prairie Regional Station in Saskatoon. The research effort is quite small when considered by itself, but in relation to the over-all program in the consideration of hundreds of similar problem areas of the construction industry, it is quite substantial. The total staff of the Division is slightly in excess of 200. Of this number, deducting technicians and supporting administrative staff, approximately 80 are research officers. The involvement of three research officers and some technical laboratory assistance on the problems of roofing represents a comparatively large percentage of the total research effort.

The two Sections concerned directly with roofing are the Organic Building Materials from Building Science, and the Construction Section in Building Practice. Several other sections in both areas of the Division's work are indirectly involved. The Structures Section in particular is interested in the effects of building movements and roof structure deflections, and the Building Services Section, principally concerned with air, heat and moisture flow in building materials, is interested in that aspect in relation to roof insulation.

Construction Section

The Construction Section has been receiving inquiries concerning roofs for a number of years from architects, engineers, builders and owners. They have been in relation to such problems as ice-damming at eaves, paving of roof terraces, roof deck construction, insulation, vapour control, and requests for information on newly-developed roof coverings and coatings. In more recent years, the number of inquiries concerning built-up roofing failures in many parts of Canada has been increasing steadily. Reports of roof failures within a year or two of construction led to field investigations of a few such roofs, and in 1961 a study was started to determine the nature and extent of the problems leading to roofing failures. This study has been carried on by reference to roofing research in other countries, examination of Canadian roofing practices, and further field investigation of roofing failures. It has provided valuable information that is being passed on to the roofing industry for application to roofing practice and also has indicated the type of additional materials research that is necessary, some of which the Organic Materials Section of the Division has undertaken.

Organic Materials Section

Asphalt research by the Organic Materials Section dates back to 1954, when studies of the weathering of roof-coating asphalts were started, using accelerated means in the laboratory, and by natural weathering at several outdoor exposure sites. The object of this study was to compare the behaviour of asphalts produced from Canadian crudes with those of known performance records.

Some of the earlier work of the Materials Section has been continued, and new studies have been started in an attempt to relate the performance of built-up roofing to the properties of the materials and their method of combination into a roofing membrane.

More specifically, in relation to built-up roofing, current laboratory activity is principally confined to five studies:

1. Durability of asphalts

2. Roof temperatures

3. Low temperature properties of bitumens

4. Engineering properties of built-up roofing membranes

5. Combined heat and moisture flow in roofing systems.

Asphalt Durability

Early work on the evaluation of the durability of asphalts has already been mentioned. The program of evaluation was extended in 1960, with additional samples set out on outdoor exposure sites at Ottawa, Halifax and Saskatoon, and an increased amount of accelerated testing. This work included redesign of the testing equipment and an improvement in the method of preparing asphalt test panels. Work has been generally confined to hot-applied asphalts, and statements in reference to durability and weathering concern that system.

Accelerated weathering is accomplished in a standard way in the laboratory by exposing thin films (0.025 in.) of asphalt supported on aluminum panels to an ultraviolet arc, and intermittently spraying with water. The radiation from the arc is such that the panels rise to a maximum temperature of 140°F and fall to 45°F when the water spray is in operation. The operation of the weatherometer is carefully controlled in accordance with an ASTM standard. The panels are examined daily for failures in the asphalt. This examination is made by a high voltage probe, which detects pinholes and cracks by producing a spark to the aluminum base. This spark can be recorded on a piece of photographic paper, and the areas that have pinholes and cracks can be assessed. An arbitrary limit for the extent of failure is set and when the panels reach this limit they are considered to have failed. The variation in time for the asphalts studied is considerable. The most durable asphalt by this method required 75 daily cycles to reach failure, compared with 21 for the least durable.

Chemical analysis of the asphalts under study was made to try to relate durability to physical properties and chemical composition. It was found that degradation was accompanied by a decrease in oil content of the asphalt, and also that the asphalts with low oil content had poor durability. The nature of the sulphur content of the asphalt also appeared to influence durability.

Natural weathering studies seem to be showing the same relative differences in durability, but there also seems to be a relation between durability and the surface pattern that the asphalt develops during degradation. The pattern appears to be a property of the asphalt, as it is present on asphalts exposed to accelerated as well as to natural weathering.

Standard tests, such as softening point, penetration, flash-point and ductility, were carried out with the hope of obtaining a correlation with durability. The only property that appeared to have a correlation with durability in these tests was ductility. This is measured by the distance to which the bitumen will elongate before breaking, when the ends of a briquet specimen are pulled apart at a specified speed and at a specified temperature. Normal test conditions are 77°F and 5 cm per min. For the harder asphalts this is a small quantity, less than 1 cm, and is not even specified in ASTM and CSA standards. The test equipment is also such that measurements of slight ductility would be difficult to make accurately in most industrial laboratories after the equipment becomes worn from constant use. If further research proves that this is important, perhaps micro-ductility equipment will be necessary.

Roof Temperatures

At Ottawa in 1960, an outdoor exposure study was started to measure roof temperatures and observe the weathering of roofing asphalts on a variety of built-up roofing systems, but principally as between insulated and non-insulated construction. Test specimens, 18 in. sq, included insulated and non-insulated roofs with rag and glass fibre roofing felts, and a variety of hot-applied asphalts and surface finishes. A continuous record of temperatures has been made for four of the specimens, which were instrumented with thermocouples to measure temperatures at the under surface of the membrane. Visual examinations of the surfaces of the specimens are made at regular intervals. The results from this investigation have not yet been completely studied and analyzed; the findings, however, can be summarized as follows.

1. A built-up roofing membrane insulated from the roof deck will attain appreciably higher temperatures as the result of solar heating than its non-insulated counterpart.

2. Emissive cooling or night radiation of roofing exposed to a clear night sky can reduce the temperature of the roofing considerably below the air temperature; with an insulated deck this reduction is as much as 15 F degrees.

3. Considered of great importance are the large and rapid fluctuations in temperature of built-up roofing membranes over insulated roof decks under varying weather conditions. Even during a normal sunny day in summer when temperatures may easily reach 150°F on a black roof, a heavy rain storm can reduce the roof temperature to 80°F or lower in less than an hour.

4. Light-coloured gravel and liquid surfacing materials tend to reduce the temperature build-up from solar heating.

5. On smooth-surfaced specimens, there appears to be greater deterioration for roofing over insulation.

It might seem that these comments are sufficient reasons to suggest that insulation should not be used between the roof deck and the built-up roofing. For other practical reasons this is not a logical conclusion, but it is evident from this work that roofing is required to undergo a large range of temperature changes, and allowance must be made for this in the design and application of roofing system.

Low Temperature Properties

During the durability studies on asphalt it was noticed that the low temperatures of winter caused cracking of the materials without any accompanying chemical change. Also about this time many cases of splitting of built-up roofing were coming to the attention of the Division. It was therefore decided to begin a study of the low temperature characteristics of the components of built-up roofing. One study is principally concerned with brittleness of bitumen at low temperatures, and this of course gives some indication of the ductility and the ability of the material to withstand deformation.

A brittle-point test apparatus devised by Fraass, and in use in Europe for a number of years, has been modified for easier operation and for obtaining reproducible results. In this test, a uniform thin sample of bitumen applied to a mylar polyester film plaque is flexed once every minute, while its temperature is reduced at the rate of 1.8 F degrees per minute. The temperature at which a crack occurs across the asphalt sample is taken as the brittle point of the material. Using this apparatus, brittle-point temperatures have been obtained for a variety of roofing asphalts, some paving asphalts, and also for coal-tar pitches.

A preliminary study has also been made of the effect of over-heating on softening point and brittle point as indicated by the brittle-point apparatus. It appears that the test might also be used to evaluate the self-healing properties of bitumens. An initial report on this work was presented to the Canadian Technical Asphalt Association in November 1962. The report has now been published in the Proceedings of that meeting (1). Apparatus has been built that can test five samples at one time and it is now in operation to extend DBR studies on the effect of brittleness on the durability of asphalt.

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(1) Jones, P.M. A brittle point test for low temperature studies of bitumens. Proceedings, Seventh Annual Conference, Canadian Technical Asphalt Association, Vol. VII, November 1962, p. 15-24 (reprinted as NRC 7741).

Engineering Properties

During 1963, in view of the reported high incidence of roof membrane splitting, a study was begun to assess the effects of temperature on strength and deformation in relation to shrinkage and embrittlement. As roofing membranes are normally classed as non-load-bearing, there is very little information available regarding the stress-strain properties. There is no doubt that they are subjected to strains, however, due to building or roof deck movements, and to temperature and moisture changes. Most of the splitting of roofing membranes has been attributed to thermal shock due to a rapid drop of temperature during cold weather conditions, when there is little or no snow on the roof. It has not been proved that this is the cause, and a study is under way to obtain more information regarding shrinkage and extensibility of roofing materials at low temperatures in an attempt to determine potential performance. Initial work is being confined to controlled conditions in the laboratory. Techniques for preparing and loading the roofing samples have been worked out; the first phase of the testing program has been completed and was reported on at an ASTM Symposium in June 1963 (2).

Tensile studies were performed on bare felts and on membranes prepared with bitumen at two temperatures, 75°F and -20°F, and using two rates of straining. The results indicate that the felt plays a major role in the strength of the membrane. At both temperatures the felts contributed 80 to 90 per cent of the strength of the membrane, although the actual strength in the case of rag felts was generally tripled when the temperature dropped from 70°F to -20°F. At -20°F the samples had almost the same tensile properties regardless of the rate of straining, indicating that little creep of the bitumen occurs at this temperature. At 75°F, creep did have an appreciable effect.

As yet it is difficult to relate these results to the splitting of real roof membranes, but they do indicate what further work is necessary to begin to assess the strains that may be occurring on actual roofs. Shrinkage due to lowering

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(2) Jones, P.M. Some engineering properties of built-up roofing. ASTM Special Tech. Publication No. 347, p. 70-78 (reprinted as NRC 8193).

of the temperature will have to be determined for comparison with the strains which the membranes exhibit at breaking. The temperature effects themselves are complicated by the nature of the membrane, which may be regarded as three components - fibre, saturant, and coating. The presence of moisture in the felts can also be a complication affecting the dimensional changes on cooling. Preliminary tests at the Division and results from other laboratories show that the shrinkage effects are not linear with temperature, but can increase at a much greater rate below the freezing point.

The presence of moisture in the felts seemed to be one of the more serious problems; a study was therefore started on the moisture absorption of felts and the dimensional changes due to moisture absorption. Work on the engineering properties of membranes has had to be temporarily halted while this investigation is carried out.

Combined Heat and Moisture Flow

For a number of years a study has been under way at the Division by the Building Services Section to determine the rate of moisture gain, and the moisture content distribution, of various insulating materials exposed to a temperature gradient, with the cold surface sealed and the warm surface open to controlled moist-air conditions. Observations are being made for a number of controlled air conditions and a number of cold-surface temperatures.

Related Work of the Division

The work of the Division is not remote from the day-to-day problems of roofers, and close contacts are maintained with the roofing industry. Of great importance in connection with roofing studies is the excellent liaison the Division has had with the manufacturers individually and through the Asphalt Roofing Technical Committee, and with roofing contractors individually and through CRCA and the provincial roofers' associations. With help from the industry and the co-operation of architects, engineers, contractors, roofing consultants, and owners, members of the Division have been privileged to examine a large number of roofing jobs exhibiting failures and also to observe roofing application practices on a considerable number of jobs under construction across the country.

It became evident early in these field studies that accurate information on conditions existing during construction and from construction to time-of-roof failure was very difficult to obtain. Even with the co-operation of manufacturers holding guarantee bond files on certain jobs, it is almost always difficult to pinpoint the factors that may have caused premature failure. From the roofs investigated it is obvious that there is no blanket solution, nor any one specific factor that causes a roof to fail to perform as expected. Field investigation of failures and observations of roofing techniques must be continued as a necessary complement to the laboratory research in order to assess the nature and extent of problems encountered by the roofing industry.

Members of the staff of the Division have served for many years on technical committees of such bodies as the Canadian Government Specifications Board, the Canadian Standards Association, and the American Society for Testing and Materials, and other such Standards bodies with an interest in bituminous roofing materials. Assistance has been given where possible in the preparation of standards and specifications, in the setting up of test procedures, and in some cases, in the testing of materials to determine the adequacy and practicability of standards and test procedures. Contacts, in many instances personal, are maintained with researchers investigating similar problems at other research organizations around the world. Le Conseil International du Bâtiment (C. I. B.), also known by its longer English title, the International Council for Building Research Studies and Documentation, has Working Commissions to study various building problems, and for the exchange of research information on an international basis. Commission W-13, for instance, is concerned with flat roofs, and the Division provides the Canadian representative on this Commission of C. I. B., as it does for many of the other Commissions.

NEW MATERIALS AND SYSTEMS

Industry research groups have also been giving roofing considerable attention in recent years. Two reasons probably account for this. First, the roofing industry is at present faced with a variety of roofing defects, all of which cannot be blamed on workmanship; and second, many new roofs of unusual contours - curved shells, domes, hyperbolic paraboloids, folded plates - have been developed by designers, and these are not always easily roofed with conventional materials.

We appear at this time to be at the edge of a new era in roofing. The plastics industries are producing new products, and new systems of application with single-ply thin films replacing the old multi-ply systems are being proposed. Some of these are factory-produced films or film-covered felts, and others, in liquid form, are sprayed, brushed or rolled on. New combinations are being introduced at such a rate that it is becoming difficult to keep informed on even the chemical and trade names used to describe them. Some of the new systems have been introduced to serve a particular function which conventional roofing can only accomplish with difficulty, but some of them are also being offered as substitutes for conventional roofing. Some of them still utilize bitumen as part of the system, but others have broken away from bitumens completely.

An increasing percentage of roofing will use these new systems over the next few years, and the success of individual roofing companies, and perhaps the future of the industry, will rest with some of them. The sales personnel of the manufacturing firms are so enthusiastic about the new products that, unfortunately, they often make fantastic claims for them. Unfortunately, too, some architects are quite gullible.

Many of the new materials hold a great deal of promise but most have not been adequately field-tested, and it is certain that there will be failures before the unworkable systems are weeded out, and the workable systems adapted to construction conditions. The promoters, in their enthusiasm, tend to forget or to ignore some of the factors that cause failure, such as building movement, trapped moisture, and poor workmanship. These factors still exist with the new as well as with the old systems. The new materials, in their turn, introduce new factors, such as dependence on thin layers of adhesive to provide water-tightness at narrow joints, bridging characteristics of fluid systems over rough surfaces and joints of structure and insulation, to mention only a few. The most encouraging thing is that, unlike conventional bituminous roofing, which had its beginnings in the use of waste products in the rebuilding of Chicago after a fire disaster, and is still largely waste products but from a different industry, many of the new products are developments of the plastics industry, designed specifically for use as roofing.

In addition to the primary function of protecting a building against the penetration of water, most of the new systems claim secondary functions such as lightness in weight, high elasticity, high reflectivity, resistance to traffic, and even easy removal of atomic fallout. The last function is probably good advertising, but other problems of fallout are such that this would be of relatively minor importance.

Bituminous-type systems that appear to offer some improvement over conventional hot bituminous roofs are the cold-applied asphalt emulsion systems and cold-applied coal-tar pitch systems. Most roofing systems using static emulsions start with a base membrane of coated asphalt felt applied over the deck or insulation with either a hot or cold asphalt cement. In some instances, where application is directly to a concrete deck, the base membrane may be omitted. In one system, asphalt emulsion and chopped glass fibres in the ratio of three gallons of emulsion to one pound of glass is applied over the base sheet or prepared deck by means of a special three-nozzle spray gun, which sprays the emulsion and glass simultaneously. In other systems asphalt emulsion is brushed on over the base sheet or prepared deck, and a glass fibre mat is embedded. Additional emulsion is applied by brushing as a second coat. Decorative appearance and light reflection in both systems is obtained by a sprayed finish coating such as acrylic paint. These systems have had limited use in Canada for a number of years. Although they provide good weathering characteristics and ease of maintenance, there are limitations in applying them. The water emulsions can only be used in above-freezing temperatures, and they set up very slowly so there is danger of wash-off in rain during the first day after application.

Cold-applied coal-tar roofing has been under development for a number of years. It recently appeared on the market in the U.S.A. for a few months, but has now been withdrawn. This product consists of a coal-tar pitch impregnated asbestos or glass fibre felt, to which a coal-tar base adhesive is applied. The unique feature of the system is the 35-mil-thick factory-applied pressure-sensitive adhesive, which eliminates the need for either hot or cold cement during application. The surface of the adhesive is covered with a disposable release paper that prevents sticking in the roll. For this reason it has been referred to as "band-aid" roofing, since application consists of peeling back the release sheet as the membrane is laid out on the roof. After the membrane is laid on the roof, the application is completed with a coal-tar pitch emulsion top coat. Colour and reflection of light are obtained by the application of a paint-type coating. Adhesion between felts is apparently very good, but some difficulties have been experienced with adhesion to base surfaces.

Neoprene and chlorosulfonated polyethylene (hypalon) systems are already being used in most parts of Canada, the oldest applications having been made three or four years ago. These are elastomeric materials based on synthetic rubbers. The basic materials were developed by the DuPont Company, but are supplied as a roofing system under various trade names by a large number of companies in the U.S.A. and Canada. Neoprene, one of the first synthetic rubbers to be produced on a commercial scale, was introduced in 1932, and is reported to have a history of good resistance to sunlight, temperature extremes, weather, ozone, and to oil and grease. Hypalon was introduced by DuPont in 1952, and is made by reacting polyethylene with chlorine and sulphur dioxide. It is reported to have all the advantages of neoprene and, in addition, can be provided in stable colours.

Neoprene can be used either singly or in combination with hypalon to form roofing membranes, but is usually used in combination. The neoprene may be applied in sheet form, or as a liquid roofing solution, but the latter is the more usual because the sheet application is extremely expensive. By far the most common technique is to apply the neoprene in solution form, using the conventional methods of brushing, rolling, or spraying. The pressure roller method is reported to be the most satisfactory and economical. Several coats are applied to build up a dry thickness of at least 20 mils (0.020 in.) for the finished membrane. The top coat (or sometimes the last two coats) is hypalon. All joints in the deck must first be caulked and taped with cotton or glass tape applied with neoprene. Some companies have experimented with a spraying technique using glass fibre and chopped into short lengths and sprayed, simultaneously, to get better bridging characteristics from the material with the hope that taping of joints can be avoided.

The weathering characteristics of this system appear to be very good when the material is applied in sufficient quantity over a suitable base. There has been some blistering when it is applied to concrete decks, and some cracking of membranes from deck movement and cracking where the membrane has sagged into joints in the substrate. Improvement in application technique can eliminate most of these faults.

There are two systems now on the market in the U.S.A. and coming onto the Canadian roofing market, which utilize a very thin film of plastic or rubber over an asbestos felt. One system utilizes a polyvinyl fluoride film (2 mils thick), factory-laminated with an adhesive to an elastomer impregnated asbestos felt, to produce a single-ply roofing membrane. This material is applied to a roof using conventional hot or cold methods. A coated asphalt base sheet has been recommended for most applications, but the promoters hope it may be possible on certain jobs to use the material without a base sheet. The material is 36 in. wide as for the standard roofing, and has a 2-in. selvage edge to allow for side lapping. Caution is required on the part of the applicator to avoid contamination of the adjoining sheets with asphalt, although the surface is fairly readily cleaned with solvents. The side laps are finally secured with a pressure-sensitive tape of polyvinyl fluoride film 2 in. wide, so it is not necessary to bring the asphalt adhesive to the edge. It is claimed that this roofing can be applied from level to vertical. The high coefficient of solar reflectivity, particularly of the white plastic film, reduces surface temperatures to such an extent that the possibility of slippage is greatly reduced.

The other system of this type has a 30-mil-thick polyisobutylene rubber film, factory-laminated with an adhesive to a latex-impregnated asbestos felt for the membrane, and to a woven glass fibre felt for flashing material. A thicker sheet of polyisobutylene without backing is also used for special fittings. The membrane is applied with a liquid polyisobutylene adhesive applied in ribbons with a special dispenser. There is a special polyisobutylene cement for use at the laps, and a third cement based on the same material for use in flashing. Colour is black, so decorative and reflective treatment must be obtained by a sprayed or rolled-on coating.

Some of the rubber companies have decided that the roofing industry is a good market for sheet rubber in varying thicknesses from 1/32 up to 1/8 in. One or two companies in the U.S.A. have been pioneering this use and have several applications, and recently a Canadian rubber company started manufacturing black and white butyl rubber roofing in Quebec. This material appears to have a good deal of promise, and is adhered to the substrate by rubber-type adhesives. The Canadian company has been manufacturing to standard width of 36 in., and material is placed with a 4-in. side lap. It appears that it might be practical to produce and apply much wider material, thus greatly reducing the number of joints on a job. The principal problem with the material to date has been its poor resistance to cracking from ozone attack. The more recent formulations by the raw materials suppliers and the manufacturers appear to have solved this problem. Chalking, due to the release of titanium dioxide pigment may be a problem with white butyl.

The above summary on new materials is far from exhaustive. Experimentation is taking place with epoxies, epoxy and elastomeric combinations, silicone rubber, liquid butyl, butyl latex, and other materials. Certainly it cannot be said that the roofing industry is standing still. It can only be hoped the roofer will not be the one to bear the brunt of the systems that fail. This is why the roofing associations must remain vigorous and active. The associations could be of great service to manufacturers, to the public, and to the roofing industry, if each member reported on his experience in application and any problems involved with these new roofing systems. It has been said that change is not naturally acceptable to all people. Those who do not expect change are frightened by it, but wise people make allowance for it, and take it in their stride.

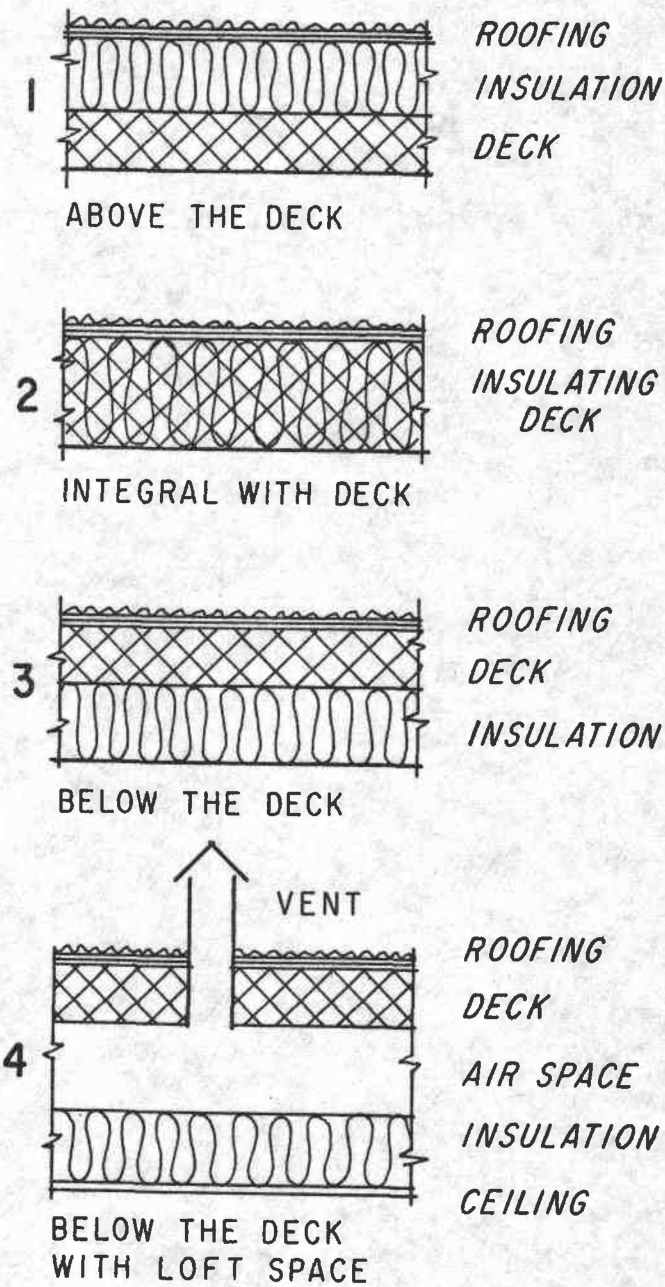
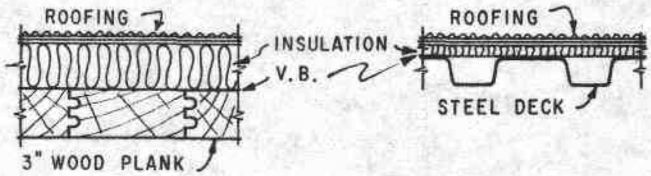


FIG. 1 ROOF INSULATION



RESISTANCES

INSIDE SURFACE FILM	*0·61*	*INSIDE SURFACE FILM*	*0·61*
3" WOOD PLANK	*3·28*	*STEEL DECK*	*0*
VAPOUR BARRIER	*0*	*VAPOUR BARRIER*	*0*
INSULATION/INCH	*2·78*	*INSULATION/INCH*	*2·78*
ROOFING	*0·33*	*ROOFING*	*0·33*
OUTSIDE SURFACE FILM	*0·17*	*OUTSIDE SURFACE FILM*	*0·17*
TOTAL RESISTANCE WITH NO INSULATION	*4·39*	*TOTAL RESISTANCE WITH NO INSULATION*	*1·11*
RESISTANCE FROM INTERIOR TO V.B.	*3·89*	*RESISTANCE FROM INTERIOR TO V.B.*	*0·61*

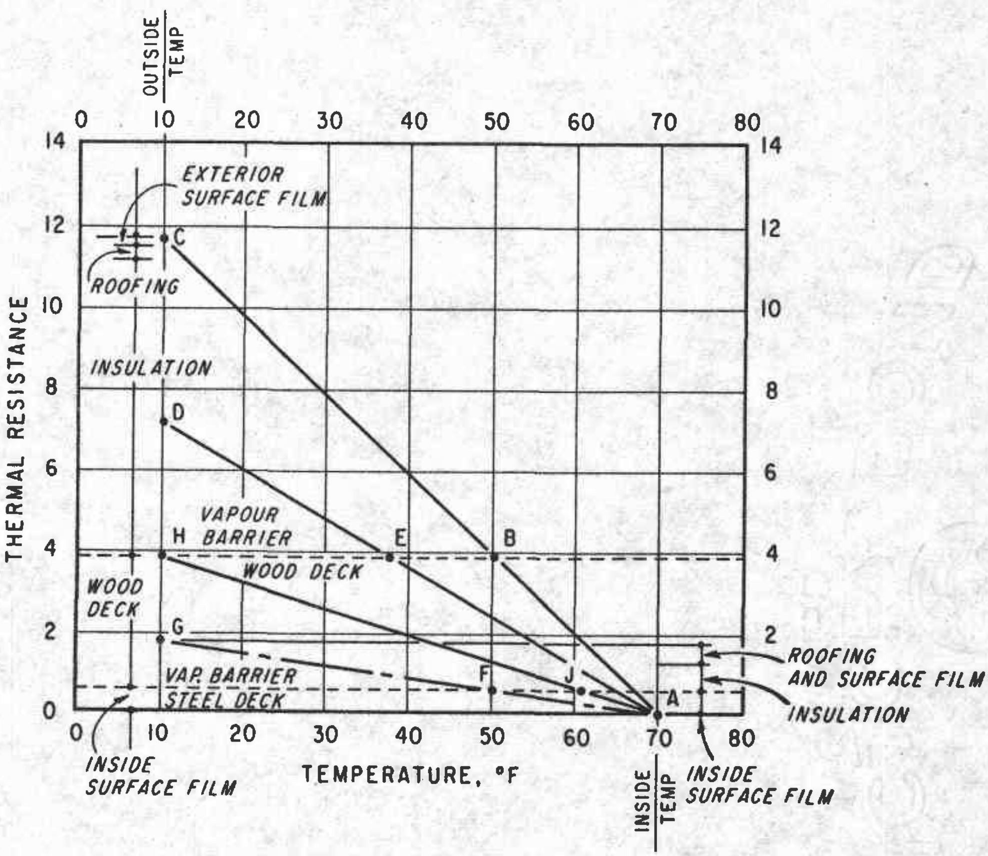


FIGURE 2 TEMPERATURE GRADIENTS THROUGH ROOFS

BR 3002-2

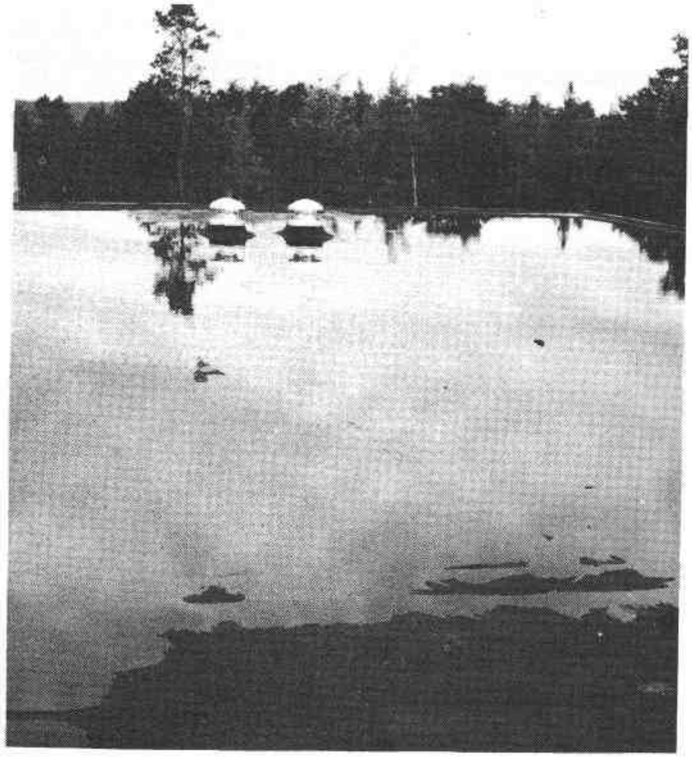


Figure 3

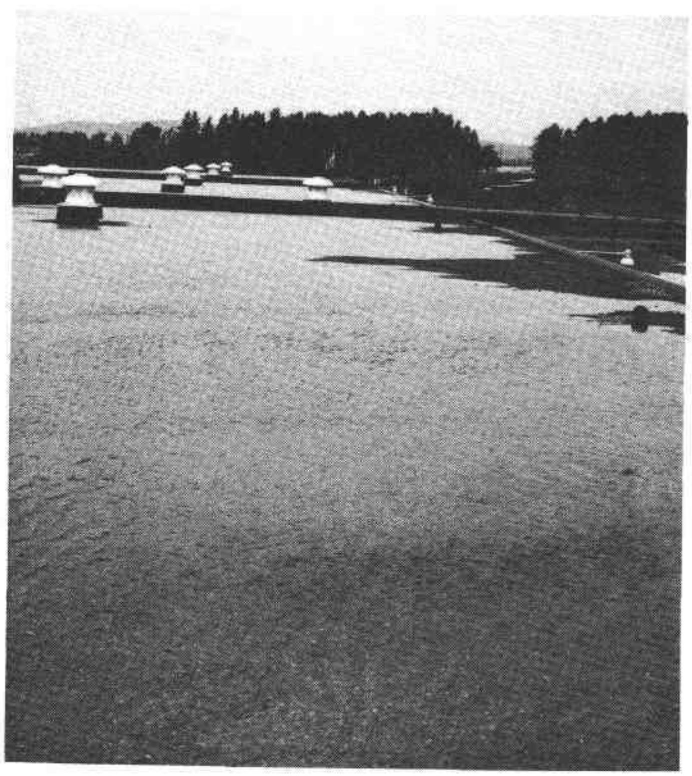


Figure 4

Two roofs, one in Central Canada and one in Eastern Canada. These flat roofs were not designed as flooded roofs.

Figure 5 Machine laying of felts by the shingle method. Usually better than hand mopping but still leaves direct path from roofing surface to substrate if adhesion is poor or wrinkles occur between plies.

Figure 6 Top pouring of bitumen with gravel spread by hand. Uniform coating is unlikely and possibility of skipped areas great.

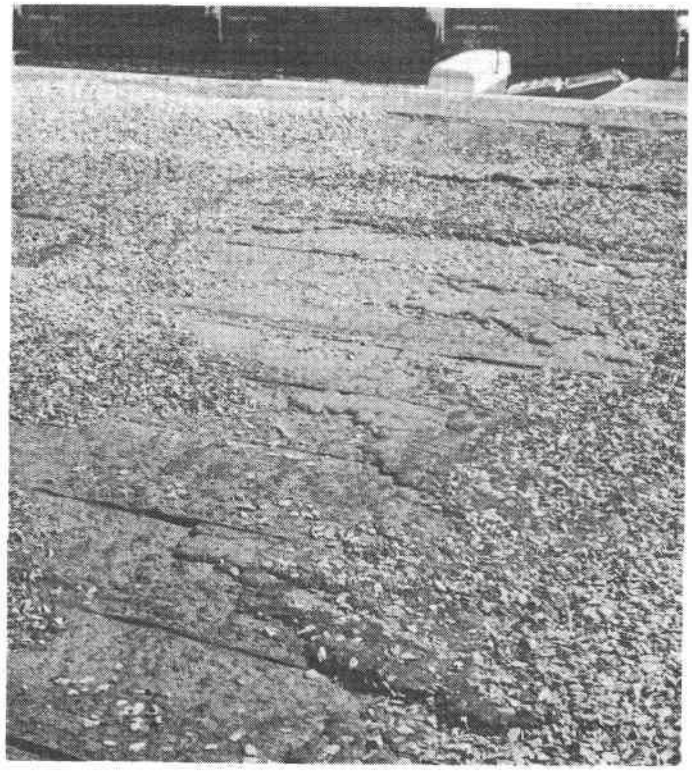


Figure 7 Result of poor gravel surfacing and wind action. Bitumen and felts are completely unprotected.

Figure 8 Because of poor flashing design, work at roof perimeter has been left for completion at a later time. Felts are unprotected and will be very much deteriorated before the job is finished off.

Figure 9

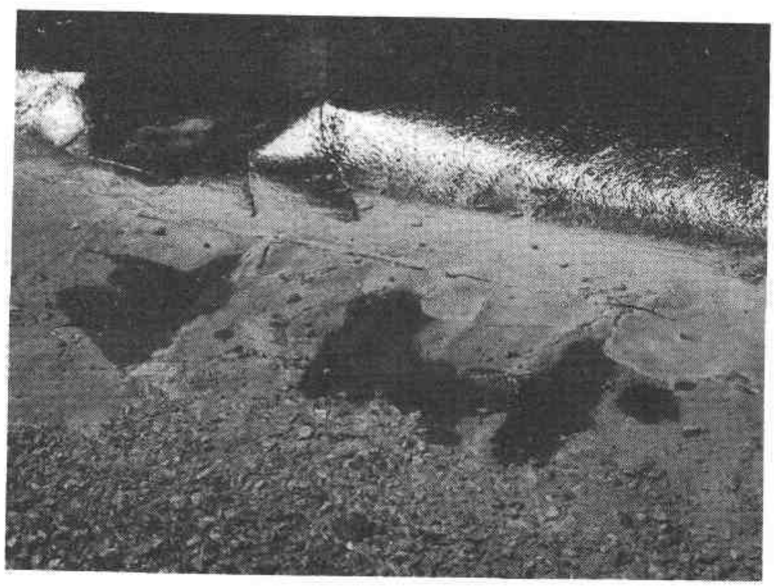


Figure 10

Both photographs illustrate poor procedure and workmanship in finishing around roof penetrations. Felts left exposed for later finishing are already wrinkled and deteriorated before the roofing job is completed. Dark areas are water squeezed out from under the side laps.

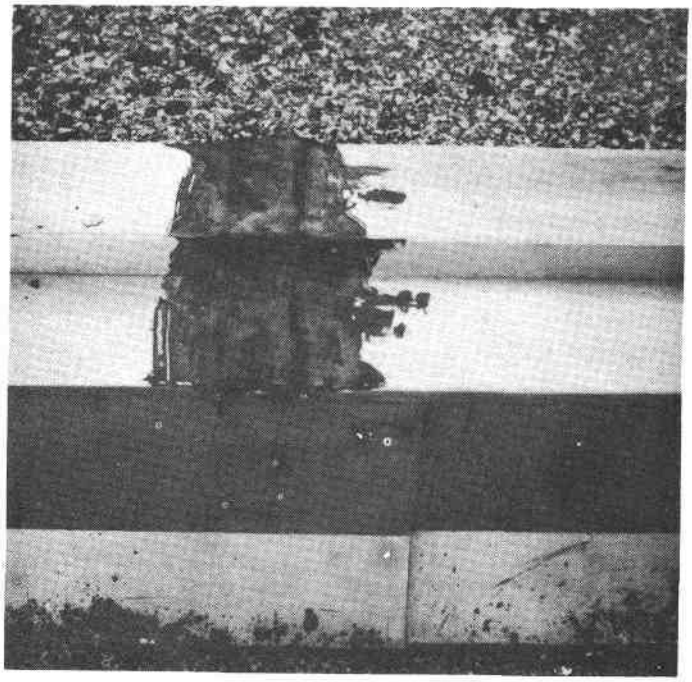


Figure 11

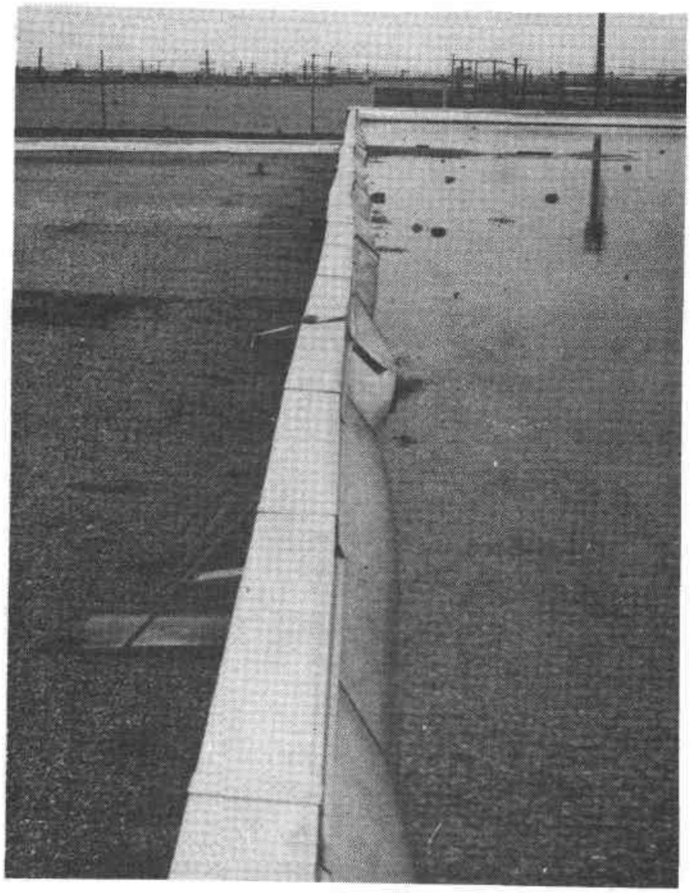


Figure 12

Both photographs illustrate flashing movement from temperature changes. In the top photo the mass of caulking at the joint is not effective in preventing water penetration. In the bottom photo note the water on the roof and the ineffective scupper drain.