

FLAT ROOFS IN THE UK AND THE INTEGRATED SYSTEM APPROACH

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Research over the past 15 years has fully identified the reasons for the problems that plagued the United Kingdom's flat roof industry with roofs constructed during the 1960s and 1970s. In retrospect, the bad results that came out of this period can be ascribed to a catalogue of errors in design, construction and use of materials.

In recent years substantial effort has been made to correlate the results of this research and translate it into applied technology. Good progress has been made in achieving this objective and we are fully justified in claiming that, during the past decade in the U.K., the flat roof and its associated materials have been the most intensively researched elements of building construction at any time in construction history.

When there is detailed knowledge of a problem and its cause, a solution usually can be found.

With the extensive knowledge available from many years of researching defects and the advancement in the performance capability of new roof component materials, flat roofs of the highest performance quality now are achievable.

Nevertheless, they must be designed and built as complete elements of construction, with all component parts fully integrated to perform in harmony with one another when the total flat roof element is subjected to the internal and external service conditions anticipated.

With the wide range of materials and methods of construction now in use, the complexity of writing a specification for any particular roof without expert knowledge has become an extremely formidable task.

At last year's Bituminous Roofing Council Conference in Brighton, England, a comment was recorded: "The industry is drowning in information, but starved of knowledge."

The main purpose of this paper is to present an idea for the organization of the necessary information so that by completing a series of checklists within a knowledge-based computer system, the essential information required by the roof designer can be easily obtained.

SUMMARY OF COMMON DEFECTS

Some of the major problems that had to be resolved can be summarized as follows:

Trapped Water—At one stage problems were experienced because of water trapped within the decks constructed of dense concrete, with a superimposed lightweight concrete to provide the required falls for shedding rainwater and at the same time provide a measure of thermal insulation.

These problems were mainly because of the fact that large quantities of water could collect on the dense concrete surface, but be concealed by the lightweight concrete, giving the impression that the roof deck surface was dry. Once

covered with a waterproof membrane it was extremely difficult to remove the trapped water.

The main solution to this problem is to provide drainage holes through the concrete deck and thus prevent the accumulation of water at the construction stage. Where such problems already exist, drying vents have been successful in tackling the areas where trapped water accumulates internally to a point where dripping of water takes place. However, the influence of such vents is very localized and their influence is very dependent upon their correct positioning.

Splitting Failure of Roof Waterproofing Membranes—A wide range of roof decks is constructed from preformed units, e.g., woodwool slabs, plywood, blockboard, lamin-board and resin-bonded wood chipboard, to which surfaces the roof covering system can be directly applied. It was with the introduction of this type of roof deck that problems due to splitting failure of weatherproofing membranes first were experienced.

The problems associated with this type of roof deck clearly established the need for weatherproof covering materials of a higher performance standard than the traditional roofing felts.

Introduction of Thermal Insulation Materials—The problem also was exacerbated by the introduction of a wide range of thermal insulating materials which, due to their high thermal efficiency, resulted in the weatherproof membranes being subjected to a wider range of temperature variation, particularly in summer months when temperatures within the membrane system can rise to as high as 80C (176F).

Some of the insulating materials caused premature failure of the roof coverings because of substantial thermal movement at their joints.

CONDENSATION

Problems with roof structures based on moisture-sensitive materials became commonplace with the increased use of central heating and improved thermal insulation standards.

Because of the absence of significant ventilation within such buildings, humidity levels and internal/external temperature differentials increased, resulting in condensation wetting.

Some of the roof deck materials proved to be unsuitable because of distortion and rotting, and they no longer are used.

Many existing panel deck roofs designed as "cold" roofs, with the thermal insulation at ceiling level, were not provided with the cavity ventilation which is essential for this type of roof. Premature failure of such roofs often resulted.

This type of failure led to the breakdown of the weather-

proof covering often coupled with severe deterioration of the structure itself.

OTHER PROBLEMS

Problems relating to damage from construction traffic and subsequent roof trafficking for which the roofs in question were not designed have been commonplace.

Unsuitable detailing and faulty execution of work also has been a common fault.

One of the most outstanding problems of all has been the use of unsuitable materials.

This summarizes the situation in the 1960s and 1970s, but roofs constructed during this period represent the major stock of flat roofs in the U.K. and the poor performance of these roofs has a major influence on the current image of flat roofs.

CURRENT SITUATION

Up to the end of the 1970s, although extensive work had been undertaken in identifying problems and finding solutions, much of the research was fragmented and details were not readily available, so it was difficult to achieve any significant correlation on a national scale.

However, with the increased commitment in recent years from all major parties concerned to resolve the problems associated with flat roofs, we fortunately made substantial progress in fitting together the pieces of the flat roof jigsaw puzzle.

The most important requirement to overcome the deep-seated problems relating to flat roofs has been to achieve a full-scale national involvement of all relevant parties toward establishing correct methods for the design, selection of materials, and construction of flat roofs.

Some of the most significant events that have enabled us to make real progress can be summarized as follows:

- The National House-Building Council published their Practice Note No. 13 in December 1980 covering "the construction of flat roofs and pitched roofs with a fully supported continuous weatherproofing membrane." This was issued for designers and builders in the private sector and was aimed at preventing defects.¹

- The national need later was met by the Bituminous Roofing Council which was formed at the beginning of 1982. BRC has proved to be extremely successful in establishing itself as the leading trade association concerned with promotion of good practice in the design and construction of flat roofs. BRC organized three joint seminars with the British Standards Institution, the Royal Institute of British Architects and The Royal Incorporation of Architects in Scotland, which proved to be very successful.

They organized a major international conference at Brighton at the end of August 1984. They are in discussion with RIBA to set up training courses for architects.

The main theme that has been developed by BRC is the integrated system approach for flat roofs. When designing a flat roof, it is important that the roof be treated as a composite unit and to recognize that the long-term performance of each material is interdependent with the other materials involved. Also one must remember that internal conditions of the structure can be influenced by condensation, thermal movement, and the applied stresses from the use of the building.

Eight Technical Information Sheets now have been issued on various important design aspects for flat roofs. Their effectiveness in providing essential information to a very wide circle of recipients has been acknowledged from independent sources.

- British Standard Code of Practice BS 6229, "Flat Roofs with Continuously Supported Coverings," was published in December 1982.¹

BRITISH STANDARD SPECIFICATIONS

B.S. 6229 covers the general principles of flat roof design, specifications for materials and components, and principles of workmanship. The design section is fairly comprehensive and considerable coverage is given with regard to thermal design and the control of condensation. The scope of the document covers weathertightness, drainage, thermal and sound insulation, condensation control, structural support, fire precautions, maintenance and repair. About half of the document is devoted to the subject of thermal insulation and the control of condensation.

Conformity to British Standard Specifications is a mandatory requirement of many contracts. B.S. 6229 represents a major advance in U.K. practice. The main points covered by the code are:

Types of flat roof

Three types are covered by the code, each type having particular design requirements.

- **Cold roof**—where the principal thermal insulation is immediately above the ceiling.
- **Warm roof**—where the thermal insulation is immediately beneath the roof covering.
- **Inverted roof**—where the thermal insulation is above the roof covering.

Condensation

Condensation is identified as one of the principal causes of failure of flat roofs. Substantial attention is given in the code in the prediction and control of condensation.

Protection Against Trapped Moisture

The code gives guidance on the avoidance of trapped water and recommendations relating to drainage holes in concrete decks are provided.

Regarding ventilators, the code states, "Reliance should not be placed on drying out trapped water by roof ventilators."

In the author's experience vents can be very useful if properly applied.

General

All other relevant aspects are covered either directly or by reference to other Specifications or Codes, for example CP 144: Part 3, "Built-up Bitumen Felt."

- **B.S. CP 144: Part 3**—"Bitumen Built-Up Felt Roof Coverings." This code is under revision and the new code will cover "The Design, Construction and Maintenance of Fully Supported Built-Up Bituminous Roof Coverings."

This code will be a key document in that it will cover essential information relating to roof deck materials and waterproofing, including the following topics: insulation materials, their installation onto a vapor barrier, vapor check or direct to deck; selection of membrane materials

for BUR, including polyester-base roofings with both standard bitumen and polymer-modified bitumen coatings, and bitumen bonded polymeric roofings; and the method of attachment of the BUR to either the deck or insulating materials. This will ensure proper integration of the various insulating materials in relating to both roof-deck and roof covering materials, and the correct selection and use of surfacing materials.

RESISTANCE TO FATIGUE FAILURE

The use of high strength, high fatigue-resistant membranes with correct methods of attachment will prevent splitting failure and wind damage. Much higher levels of resistance to other physical damage also are achieved by high strength roof coverings, and for the long-term protection of trafficked roofs, paving slabs or concrete tiles will provide the necessary protection.

The correct method of attachment is of considerable importance and in certain cases 13-millimeter thick fiber insulation board is used either as a thermal protection layer, as in the case of expanded polystyrene, or to enable a full bond to be used where a partial bond is unacceptable. The following table provides examples.

Roof Deck	Requires 13mm Fibre Insulation		Built-up Roofing Fixing of 1st Layer	
	Flat	Above 10°	Flat	Above 10°
Plywood				
Chipboard				
Woodwool ¹	No	Yes ⁴	Part Bond	Full Bond
Screed				
Concrete				
Timber	No	No	Nail	Nail
Asbestos			Full Bond	Full Bond
Cement	Yes ⁴	Yes ⁴	Full Bond	Full Bond
Thermal Insulation				
Fibre board				
Cork	No	No	Full Bond	
Cellular Glass				
Glass or Mineral ²			Full Bond plus Mechanical Fixing	
Fibre Perlite ^{2,3}	No	No		
Polystyrene				
Extruded	Yes	Yes	Full Bond	Full Bond
Prefeltd				
Phenolic				
Polyurethane				
Bitumen Glass	No	Yes	Partial Bond	Full Bond
Fibre Faced				
Isocyanurate				
Bitumen Glass	No	Yes	Partial Bond	Full Bond
Fibre one side				
Aluminum the Other				
Cellular Concrete				
Lightweight Aggregate Concrete	No	—	Partial Bond	—

¹ Prescreeded or prefeltd

² These boards are of a compressible nature. Use with category 2, 3 or 4 roofings only.

³ These boards have a low strength surface. Use category 2 first layer with mechanical fixing.

⁴ 13mm fibre insulation board is unnecessary if other insulation is used, unless required with that particular insulation.

Method of attachment of BUR in relation to roofdeck or insulation contact surface.

ORGANIZATION OF AVAILABLE KNOWLEDGE

The new British Standard Specifications will be wide-ranging, and in view of the variety of roofdecks, insulating materials, roof coverings, and the many standards and codes relevant to B.S. 6229, the complexity of writing a specification for any particular roof without expert knowledge will become an extremely formidable task.

Communicating this knowledge in a usable form to architects and roof designers is an equally formidable task, and in order to employ the integrated system approach effectively on a national scale, substantial simplification is necessary.

The use of computers was discussed at the BRC Brighton Conference in August 1984, and two papers relating to communication were particularly interesting^{5,6}.

Before computerization can be achieved, the information must be put into a suitable format so that the various pieces of information required to constitute a complete roof specification can be easily retrieved in a form that is compatible for assembly as a complete and comprehensive document.

This paper presents an idea for the organization of necessary information so that it can be catalogued, indexed and recovered by the completion of appropriate questionnaires and checklists by the architect, designer or builder to provide the correct specification for the building and roof in question. Wherever possible, the requirements relating to each aspect of the specification are translated into a series of model specifications or specification parts, so that the appropriate parts can be put together.

CONSTRUCTION OF SPECIFICATION

The construction of the specification first requires knowledge of the performance requirements for the particular roof, which should be provided by the first two sections relating to internal and external conditions.

Primary Considerations	Influencing factors
Internal conditions	Thermal design—control of condensation Roof effluents from factory process
External conditions	Use of roof Structural loading requirements Roof slope and drainage Movement joints Exposure—wind loading
Slope and drainage	Roof zone, rainwater outlet positions
Movement joints	Size of roof and plan

Specification requirements

Choice of: Roof deck	Type of building and use of roof, e.g., inaccessible, terrace, car park
Type of roof	Cold, warm, inverted
Vapor barrier	None, vapor check or full vapor barrier
Thermal insulation	Type and thickness
Waterproof covering system	Durability requirements A, B or C
Surface finish	Use of roof

Internal Conditions

British Standard 6229 states, "experience has shown that condensation is one of the principal causes of failure of flat roofs. Particular attention is therefore given in this Code to the prediction and control of condensation and to the importance of careful construction to avoid trapped water." Section A.2.5.2 together with Table 7 is quoted as follows.

"A.2.5.2 Indoor climate. For normal conditions of occupancy and arrangements of windows and ventilation, the indoor conditions given in Table 7 may be adopted for the purpose of condensation analysis.

"Higher humidities are generated in kitchens, bathrooms and laundries, where different conditions may apply unless additional ventilation is provided.

"Where adjacent compartments under a common roof have different indoor climates, the design of the roof as regards condensation control should be based on the more severe condition."

Type of building	Temperature °C	Relative humidity %	Vapor pressure kPa
Houses and flats	20	55	1.285
Offices	20	40	0.935
Schools	20	50	1.169
Factories and heated warehouses	15	35	0.596
Textile factories	20	70	1.636
Swimming pool halls	25	70	2.219

BS 6229—Table 7 Indoor notional psychrometric conditions for flat roof design

A method of moisture-gain analysis is provided based on the climate given in Table 7 and the following outdoor notional psychrometric conditions for flat roof design.

Notional season	Temperature °C	Relative humidity %	Vapor pressure kPa	Duration days
Winter	-5	90	0.361	60
Summer	18	65	1.341	60

BS 6229—Table 6 Outdoor notional psychrometric conditions for flat roof design

Limits for condensate retention are set at:

0.5kg/m²—non-fibrous and closed cell materials

0.35kg/m²—fibrous materials

Formulas are provided for calculating theoretical winter condensate and theoretical summer condensate and, providing that the drying out of condensate during "summer conditions" brings the net accumulation to less than the figures quoted, then the "self-drying roof principle" is recommended omitting any vapor barrier.

Model specifications can be provided covering the more common conditions together with the choice of thermal insulation materials and appropriate thicknesses to meet regulation requirements for energy saving purposes.

External Conditions

The next stage in the specification-building process is to

establish the degree of accessibility and anticipated traffic. This can vary from a situation where no access is provided other than that necessary for cleaning and repair to heavily foot-trafficked areas, roof car parking or shop delivery service areas at roof level.

The roofdeck materials commonly used in the U.K. are as follows:

	Index Ref.
■ In-situ concrete with or without screeded finish	3.02
■ Hollow tiles and beams and precast beams with screeded finish	3.03
■ Timber	3.04
■ Plywood	3.05
■ Metal Decking	3.06
■ Wood wool slabs	3.07
■ Wood chipboard	3.08

Except for the simplest of roofs, the roofdeck design demands the services of a structural engineer.

The structural engineer is required to give full consideration to the requirements for falls, drainage and expansion joints and to ensure that there is no incompatibility between the positioning of rainwater outlets and other structural elements, e.g., expansion joints, parapets, roof lights, pipes or other roof projections.

The depth of the total roof zone will be dependent upon the pattern of falls and drainage outlet positions. It is essential that this section of the design process be settled at the commencement of a roof design because of its influence on many other parts of the building.

Once the roofdeck construction together with falls and drainage requirements have been established, the specification-writing process can be continued.

Specification Build-up

At first stage, which relates to internal conditions, the thermal insulation requirement and the position regarding the need for a vapor barrier will be established. This will identify:

- the thermal insulation material
- its required thickness
- the method of attaching the insulation or vapor barrier to the roofdeck
- the method of attaching the first layer of build-up roofing to the thermal insulation.

ROOF WATERPROOFING SYSTEMS

The various roof waterproofing systems are covered in the same way by various pages giving the essential specification details for the materials and installation requirements. Pages also will be provided for the various waterproofing detail requirements which can be called up as required.

SURFACE FINISHES

The same process will apply to surface finishes. Full details regarding the materials and their application will be covered in suitable form.

WORKING DOCUMENTS

The complete assembly of specification parts will provide a set of working documents for the actual construction of the roof. They also should provide the necessary detail for any quality control system that may be required.

On the completion of the work, the specifications will be suitable for passing on to the building owner in order to give complete construction details should they be required at any time in the future in relation to modifications of the building.

REFERENCES

- ¹ National House-Building Council—Practice Note 13—“Construction of Flat Roofs and Pitched Roofs with a Fully Supported Continuous Weatherproofing Membrane”—December 1980.
- ² Tarmac “Flat Roofing—A Guide to Good Practice”—January 1982.
- ³ British Standards Institution—B.S. 6229—“B.S. Code of Practice for Flat Roofs with Continuously Supported Coverings”—December 1982.
- ⁴ European Union of Agrément UEAtc—“M.O.A.T. 27 General Directive for the Assessment of Roof Waterproofing Systems”—January 1983.
- ⁵ D. Bullivant—“The Communication Package”—Bituminous Roofing Council-International Flat Roof Conference—Brighton, August 1984.
- ⁶ M. Nutter—“Use of Computers for Selection of Roofing Systems”—BRC International Flat Roof Conference—Brighton, August 1984.