

CONCRETE ROOF TILE DEVELOPMENTS AND PITCHED ROOF TECHNOLOGY

R.K. GUNN

Redland Roof Tiles Ltd.
Surrey, England

The roof environment can be considered in terms of a range of performance factors which can be measured and simulated under controlled test conditions.

Modern concrete roof tiles can be designed and manufactured at high speed under highly automated, quality controlled conditions to produce a roofing product to meet exacting roof performance factors.

The development of a dry, mechanically fixed roof by the use of novel roofing fittings and accessories to complement the roof tiles minimizes workmanship errors and achieves low cost, high performance and long lasting roofs in a wide range of climates and roof environments.

The impact of microcomputers, the need for energy conservation and the trend toward higher performance yet environmentally sympathetic roofs in the future, must also be considered.

SUMMARY

The roof is the most exposed element of a building. Therefore, it demands high technical and design specifications for both the individual product elements and for the roof as a whole in order to achieve a satisfactory design life.

Roof environmental factors have been identified, and simulated test conditions proposed along with the required performance criteria for concrete roof tile products and roof accessories that are necessary to meet these roof factors.

A dry, mechanically fixed, pitched roofing system can be designed to achieve high performance in a wide range of roof environments.

THE ROOF ENVIRONMENT

Aesthetic considerations influence the roof environment by modifying the wind loading and driving rain performance as well as resistance to the elements. These factors have a most important affect on the function and life of a roof. Aesthetic factors can be divided into:

Location: the degree of exposure; the effect of other buildings or land masses; the surrounding topography; and whether the environment is rural, marine or industrial.

Form: the shape of the building and roof; the pitch of the roof; duo or mono pitched, the height of the building; verge or eaves overhangs; and whether roof details such as parapets, dormers have been included.

Texture/color: the profile of the roofing elements, flat or contoured; the surface finish; single lapped interlocking tiles or double lapped non-interlocking tiles; tile step height; tile size and whether dark, light or random colored.

The other roof performance factors to be considered are:

Weather-tightness: to driving rain, deluge rain and resistance to wind load forces are probably the most impor-

tant factors to be considered in the United Kingdom (U.K.) A wind tunnel was designed and built in 1964 to study the effects of wind and rain on roofs.

The simulated roof conditions are based on real U.K. field station data which has been verified by the Meteorological Office. Ongoing work will enable these conditions to be updated as the knowledge of the roof microclimate increases. A method of collecting wind speed and related rainfall rates at two-minute intervals has been developed.

The worst driving rain index recording in the U.K. was in Plymouth in 1957¹ where $0.404 \text{ m}^2 \text{ S}^{-1}$ was recorded. The driving rain index in the test has been set at $0.509 \text{ m}^2 \text{ S}^{-1} \pm 25\%$. A 1-square-meter section of roof is subjected to a rainfall rate of 38mm per hour associated with a wind speed of 13.4 meters per second for a period of 1 hour. This equals $0.509 \text{ m}^2 \text{ S}^{-1}$.

A deluge test assesses the performance under short-term high rainfall rates without wind. The simulated rainfall rate of 225mm per hour for a period of two minutes equals the worst case condition in the U.K.²

All roof tiles are subjected to a standard permeability test before testing. A 2-square-meter area of roof experiences 75mm per hour of simulated direct rainfall and 150mm per hour of simulated accumulated rainfall for two hours.

A semi-quantitative visual inspection of the rear surface is then made which allows no more than 25 percent of the underside of any tile to be damp or have any observable free water.

Wind loading: three modes of wind load must be considered to establish the satisfactory performance of a tile roof system.

To establish the *resistance* to wind load gusts, a wind pressure of up to 2.25 k Pa is applied across a test roof of 4 square meters. The pressure differential can be applied within 0.1 second.

Surface wind speeds up to 60 meters per second are applied to a 1-square-meter roof. This test establishes the maximum satisfactory performance of the roof tile system to assist the correct specification of a pitched roof in a location where the maximum wind speed conditions have been established.⁴

A fluctuating wind load test is applied to establish the satisfactory performance of the interaction between mechanical fasteners and roof tiles, under repeated extreme loads.

Structural Stability

All roof structures in the U.K. must be designed to withstand the anticipated dead and imposed loads.⁵

Dead load includes the mass of the roof tiles, roof underlay, battens, rafters, ceiling and water tank and an allowance for stored goods in the roof space.

Imposed load takes account of any external loading such as wind loading and an allowance for snow loading. In the U.K. the design snow load is 76.5 kg/m^2 on plan, whereas in Scandinavia, Austria and Canada the imposed snow load to be considered is significantly greater.

Table 1 indicates the roof load on the rafter expressed on plan. Data is based on a 30 degree pitch roof for a range of typical U.K. roofing products.

In addition to these roof loading requirements, the roof and its components must have adequate strength to withstand handling, transportation and roof maintenance traffic.

A transverse strength expressed in Newtons based on a three-line load test³ for wet samples requires:

2.1 x effective width (mm) for double lap tiles

3.2 x effective width (mm) for single lap tiles

Concrete roof tiles which comply with this minimum requirement have been found to provide a satisfactory product.

Fire and Lightning

Non-combustible and external fire rating of S.A.A. with respect to spread of flame and fire penetration⁶ enables a roof tile to be used unrestricted in the U.K. for both roof and wall cladding applications.

Roof components which are good electrical conductors can provide an increased lightning hazard unless adequately grounded. No special precautions are required for concrete or clay products which are poor electrical conductors, on low rise buildings.

Ventilation

Roof space condensation has become an increasing problem in new, modern buildings. This is a result of environmental and design changes made to reduce energy consumption. Roof space condensation can threaten the safety and durability of the roof structure, ceilings and decorations as well as the thermal conductivity of the insulation material.

The most efficient and effective method of controlling roof space condensation is to provide adequate natural air ventilation. B.S. 5250:1975¹⁷ details the minimum equivalent opening requirements at low and high level, and requires roof ventilation products to be designed to give a low air flow resistance, prevent access by birds or large insects as well as providing a continuous weatherproof path from the roof space to the external atmosphere without affecting the integrity of the other roof elements.

A quantitative method of establishing the condensation rate and air ventilation rates has been developed.⁷

Thermal Movement

The design of the roof components and roof system must accommodate the anticipated thermal expansion created by roof surface temperatures. The surface temperatures of dark colored concrete products can be expected to reach over 70C in Europe.⁸

Comfort

Some 25 percent of the heat loss from domestic dwellings in the U.K. can be lost through the roof. The upward design "U" value, or thermal transmittance, for a U.K. domestic roof at present⁹ must be not greater than $0.35 \text{ W/m}^2 \text{ C}$. In many countries with higher energy costs, the "U" value is

significantly lower. In tropical climates the downward "U" value of the roof system must also be considered to prevent high solar heat gain during the day. The color and texture of the roofing elements also can help prevent solar heat gain.

Sound is an important environmental nuisance. A roof must be designed to attenuate both internally and externally generated noise to acceptable levels.

The average sound insulation within the 100- to 3150-Hz frequency range for a pitched and thermally insulated tiled roof will be about 40 dB¹⁰. The sound generated at the surface of a roof element by wind, thermal movement or impact by rain or hail must be within acceptable limits¹¹. Thin, lightweight materials may create larger reverberations than thicker, heavier roof elements. The roof space in a pitched roof also will assist in controlling these reverberations. The acceptable sound absorption levels will vary with the use of the building.

Allowances also must be made for light and ventilation openings.

The shape, orientation, pitch and design of the roof including verge and eaves overhangs influence the solar gain through the walls and windows of a building by modifying the degree of shading.

The roof elements can have a significant adverse affect on the attenuation of radio and TV signals. Good electrical conductors, such as metal sheets or metal foil lined elements can reduce or prevent the reception from internal and loft located antennae and can produce random signal reflections, ghosts. Natural materials which possess magnetic properties, such as some natural slates, can exhibit similar effects.

Being poor electrical conductors, concrete and clay elements have virtually no affect on signal attenuation. However, all wet roof surfaces will produce some signal attenuation to internal antennae. Actual attenuation will depend on the signal strength and wavelength as well as building parameters.¹²

Durability

Over the design life of a building roof elements will tend to exhibit natural weathering and slight color changes. However, materials used in roof construction must be sufficiently durable so as not to be adversely affected by the following factors.

Materials which have a low water absorption and are not laminar in structure, dense concrete, for example, will resist frost action. Satisfactory use has been achieved in Scandinavia where prolonged freeze-thaw cycle temperatures down to -20C are experienced. ASTM C67-66 provides one test method to assess frost resistance.

The risk of hailstone damage in the U.K. is low but on the highveldt in South Africa concrete roof tiles have satisfactorily resisted an impact energy of 20 joules, equivalent to the terminal velocity of a 45mm diameter hailstone.¹³

Roof elements must resist extreme surface temperatures. Surface temperatures on dark colored concrete tiles under still air conditions of 70C have been measured in Europe and over 80C in South Africa.

The roof elements, including polymer based components, must be unaffected by prolonged exposure to ultra-violet (U.V.) radiation. A variety of commercially available apparatus are available for U.V. testing.¹⁴

of sulphur and nitrogen oxides emitted by industrial processes, is increasing. Peak sulphur dioxide levels of 300 to 500 ppm are common in the U.K. and levels of 1000 ppm have been recorded in London during the last 10 years¹⁵. An acid rain test based on 1000 ppm of sulphur dioxide has been devised.

The design of roof should prevent the access of birds or rodents (maximum gap:16mm) and large insects such as wasps and bees (maximum gap:4mm). The material must not be edible, subject to attack by birds, rodents or insects, and be immune to biological degradation.

THE MODERN CONCRETE ROOF TILE

Concrete is not a new building material. It was first used by the ancient Greeks and Romans over 2000 years ago. With the collapse of these great civilizations, it fell into disuse until it was rediscovered during the 19th century with the emergence of the industrial revolution and availability of machine power. The first concrete roof tiles were handmade by Kroher in Southern Bavaria during the 1840s and based on a diamond pattern.

The modern concrete roof tile is now designed and made in highly automated and controlled plants at speeds well in excess of 100 tiles per minute.

Design Features

High performance is achieved by designing roof tiles so that:

Based on wind tunnel experience the top and bottom profile of single lap interlocking tiles should provide gaps less than 2.5mm when laid to prevent the ingress of driving rain.

The number, position and size of anti-capillary ribs and grooves at the rear tail of the tile can significantly improve the driving rain performance of a tile by providing discrete tranquilization chambers to arrest wind driven rain.

Head = upper most edge or top end.

Tail or butt = lower most edge.

The tile interlock should be designed with minimum gaps, optimum lateral shunt (± 2.5 mm) and maximum strength for optimum water carrying capacity and resistance to driving rain.

Maximum resistance to wind uplift is achieved by optimizing the tile mass to front end thickness ratio and achieving a center of gravity which is towards the tail of the tile.

Surface finish and tile profile also have a significant effect on driving rain and wind load resistance by modifying the air velocity and local pressure coefficients close to the roof surface.

Smaller tiles, such as 265mm x 165mm or 380mm x 230mm, are preferred where there are many roof details. This minimizes the need for cutting and simplifies setting out. Larger units, 417mm x 330mm for example, permit larger roofs to be laid more quickly.

The design must also consider the need to satisfactorily stack and mechanically handle the product in the plant and during transport to the roof.

Manufacture

Sand must be free of deleterious materials and graded to achieve ease of manufacture at high speeds and to provide minimum voids on compaction.

Portland cements which offer a high early strength devel-

opment and a low shrinkage factor are preferred.

Inert inorganic oxide pigments which offer a high staining power and are resistant to normal weathering and atmospheric conditions are required.

Clean water free of deleterious salts is necessary to hydrate the cement.

The wet concrete is compacted and continuously extruded, at speeds greater than 100 t.p.m., onto a line of profiled moulds by a microprocessor controlled tile machine that exerts a pressure in excess of 500 kPa onto the wet tile. This produces a high density product.

Specially designed random color injector machines provide integral random color products. Batch type curing chambers are fully instrumented and controlled to produce a high strength, low permeability and dimensionally accurate concrete roof tile in less than 12 hours. This is achieved in a 40-degree C and high humidity environment. The cured product is separated from its mould and treated to remove efflorescence salts prior to further natural maturing for one to two weeks.

The intrinsic strength, durability and other relevant physical properties of the modern concrete roof tile are achieved as a direct result of design features, materials of fabrication and the manufacturing process.

PITCHED ROOF DEVELOPMENTS

The mode, method and specifications for laying and fixing concrete roof tiles and fittings in the U.K. have been established from Codes of Practice, traditional practice, experience and wind tunnel research based on field station data.

Two significant roofing developments have been made in the U.K. during the last seven years to establish dry mechanically fixed, long life and maintenance free roof specifications.

Dry Mechanically Fixed Roofs (Dry Tech)

B.S. 5534 (16) which was revised and issued in 1978 provided definitive wind uplift forces for pitched roofs. This enabled mechanical fixings to be established on a sound engineering basis for the first time.¹⁴ This code of practice also highlighted the fact that the deadweight resistance offered by bedding mortar could not be relied upon where there was a risk of differential roof movement. This provided the opportunity to design and develop dry, mortarless roof systems.

Dry ridge systems had to be developed to provide a wind load resistance exceeding 3500 N/m² which was established as the worst wind load condition in the U.K. for a typical exposed, low pitch, two-story dwelling. In addition the system had to satisfy all of the identified performance criteria expected of a roofing element.

Cloaked or dry verge systems had to be developed to provide a wind load resistance exceeding 4500 N/m².

Wind tunnel research demonstrated that a proportion of the anticipated roof wind load is absorbed by the roof underlay. The specification for the material and the laying and fixing of the roof underlay must, therefore, be considered when establishing a tile fixing specification. A number of wind load and tile fixing specifications are available to assist the U.K. roofing trade to accurately specify roof tile fixings.

To complement the dry mechanically fixed roof systems

an increasingly wider range of specially designed and tested roof fittings and accessories are being developed. These products provide sound functional roof details where, in the past, mortar would have been used.

Roof Ventilation

Roof and building condensation problems arising from energy conservation and environmental changes within dwellings already have been highlighted. The roof space condensation risk can be minimized if there is an adequate supply of outdoor air to remove water vapor at a rate at which roof space condensation would otherwise have occurred.

Calculations have been established to quantify the rate of condensation which would have occurred on the underside of the underlay, and to quantify the low to high level air ventilation rate required to prevent this condensation. These calculations were based on typical U.K. roofs in winter climatic conditions.⁷

The rate of condensation in a typical domestic dwelling in the U.K. was found to be 0.123 kg/hr which can be controlled with a low to high level ventilation rate of 90 m³/hr. This can be achieved typically with equivalent area openings at eaves and ridge of 10,000 mm²/m and 3,000 mm²/m respectively.

The increasing use of dry, mechanically fixed and ventilated concrete roof tile systems (Dry Tech) has significantly increased the speed of laying and fixing roofs, while minimizing workmanship errors. The overall benefit to the roofing trade will be low cost, high performance and long lasting pitched roofs in a wide range of climates and environmental conditions.

FUTURE PITCHED ROOFS

Future pitched roofs of dwellings and low rise buildings will need to consider the following trends.

The environmental lobby and increased consumer awareness will encourage more attention to aesthetic properties and harmony with surroundings. Traditional and vernacular designs also can be expected to return. This also may be encouraged by the increased attention to building failures as a result of innovation without adequate development.

The need to increase productivity and reduce roof maintenance costs will further encourage dry, mechanically fixed roof systems.

Comprehensive and accurate roof specifications also will be necessary, particularly on roof details, to avoid uncontrolled on-site problem solving.

The impact of microcomputers on the roofing industry will be dramatic and will affect every roofing activity. Products will be designed by computer aided design. Strength to weight ratios will be optimized. Process and quality control systems will be microcomputer controlled.

Roofing contractors will run their businesses with microcomputers, from estimation to stock control and business administration.

Buildings and roofs will become increasingly energy efficient. Natural ventilation systems will be complemented with mechanical ventilation systems inside dwellings.

The most dramatic change in pitched roofs will occur when solar heating systems become cost effective and complete surfaces of pitched roofs become solar heat collectors.

REFERENCES

- ¹ Lacy R.E. Climate and Building in Britain. B.R.E. 1977.
- ² B.S. Code of Practice for drainage of Roofs and Paved Areas.
- ³ B.S. 473.550 Part 2 1971 Specification for Concrete Roof Tiles & Fittings.
- ⁴ Redland Wind Loadings guide 1981.
- ⁵ B.S.6399:1984 Design Loadings for Buildings Part I Code of Practice for Dead and Imposed Loads.
- ⁶ B.S.476 Part 7 1971 Surface spread of flame for materials.
- ⁷ Redland Roof Ventilation guide 1982.
- ⁸ Chartered Institute of Building Services Guide Part A.
- ⁹ The Building Regulations F.5.
- ¹⁰ B.S.2750:1980. Methods of measurement of sound insulation in buildings and of building elements.
- ¹¹ B.S.3638:1963. Methods for the measurement of sound absorption coefficients in a reverberation room.
- ¹² Internal Report.
- ¹³ Internal Report.
- ¹⁴ Hirt, R.C., Schmitt R.G., Searle N.D. and Sullivan A.P. J. Opt Soc Amer July 1960 Vol 150 No 7.
- ¹⁵ The Investigation of Air Pollution—Warren Spring Laboratory April 1975-76.
- ¹⁶ B.S.5534 Part 1:1978 Code of Practice for Slating and Tiling.
- ¹⁷ B.S. 5250:1975 Code of Basic Data for the design of Buildings: The Control of Condensation in dwellings.