Building Design using
Cold Formed Steel Sections

Durability of Light Steel Framing in Residential Building

S O POPO-OLA BSc, MEng, PhD, DIC
A R BIDDLE BSc, CEng, MICE
R M LAWSON BSc (Eng), PhD, CEng, MICE, MIStructE

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The Steel Construction Institute
Silwood Park
Ascot
Berkshire SL5 7QN

Tel: 01344 623345
Fax: 01344 622944

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Why use light steel framing?

Light steel framing uses galvanized cold formed steel sections as its main structural components. These sections have been widely used in the building industry and are part of a proven technology. Light steel framing provides increased value to clients and contractors by prefabrication, which achieves high quality, accuracy and reliability.

The durability of galvanized steel sections is assured provided that they are located within the building envelope, as is the case of *warm frame* construction. The design life is then at least as good as with more traditional materials. In addition, light steel frames are free from long-term creep movement, and they are not subject to rot or insect attack.

Light steel framing combines the benefits of lightness, flexibility in internal planning, long span capabilities, robustness, and durability, together with speed of construction on site. The steel sections are dimensionally accurate and have reliable structural properties. Steel is a recycled and recyclable product, and can be adapted to a wide range of applications.

The publications in this series present the important design aspects of the use of light steel framing in residential and low-rise buildings, and provide case studies on a wide range of recent applications of this technology in new-build and in renovation.

FOREWORD

This publication presents performance data taken from several projects carried out by Corus (formerly British Steel), DETR, BRE, ECSC and SCI in order to give specifiers confidence that the standard galvanized (zinc) coatings applied to light steel sections are able to achieve a design life well in excess of 100 years within the *warm frame* building envelope.

The work of collecting and presenting the data was carried out by Dr S O Popo-Ola, Mr A R Biddle and Dr R M Lawson of The Steel Construction Institute and Mr R F Gray as Consultant to SCI. The work was funded by Corus Colors (formerly British Steel Strip Products).

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This publication provides information that supplements the detailed design information in the following SCI publication series on cold formed sections:

- *Design of structures using cold formed steel sections* (SCI P089, revised)
- *Building design using cold formed steel sections: Worked examples to BS 5950: Part 5: 1987* (SCI P125)
- *Building design using cold formed steel sections: Acoustic insulation* (SCI P128)
- *Building design using cold formed steel sections: Fire protection* (SCI P129)
- *Building design using cold formed steel sections: An architect's guide* (SCI P130)
- *Building design using cold formed steel sections: Construction detailing and practice* (SCI P165)
- *Over-roofing of existing buildings using light steel* (SCI P246)
- *Over-cladding of existing buildings using light steel* (SCI P247)
- *Value and benefit assessment of light steel framing in housing* (SCI P260)
- *Modular construction using light steel framing: An architect’s guide* (SCI P272)

Other data on durability of galvanized steel are being collected under a ECSC project entitled *Elevated and Low Temperature Performance of Coated Strip Steel Products*, which is being carried out by Corus (Welsh Technology Centre), Rautaruukki Oy (Finland) and ITC (Portugal).

Surveys are continuing on other applications of light steel, including suspended ground floors and modular construction.

Suppliers of light steel framing for housing are listed on pages 48-50.

CONTENTS

SUMMARY

This publication presents a summary and analysis of research findings on the durability of galvanized cold formed steel sections used in housing to deduce their design life. These sections are produced from pre-galvanized strip steel. It reviews reports and publications from research projects carried out by Corus (formerly British Steel), DETR, BRE, ECSC and the SCI on zinc coated cold formed steel products. New data have also been gathered from measurements on houses and similar buildings that have used galvanized steel components.

The performance of galvanized (zinc coated) steel components within *warm-frame* applications is very good. This research shows that the predicted design life of the standard G275 coating, based on the measured loss of zinc from the strip steel, is over 200 years, provided that the building envelope is properly maintained. The evidence for this conclusion is based on measurement of zinc loss on light steel frames in various applications and locations. A formula for the loss of zinc over time in areas subject to low condensation risk is presented.

The following table summarises the expected design life of galvanized steel sections in common applications in buildings. Steel does not shrink, warp, or creep under load, and therefore does not contribute to cracking or deterioration of the non-structural elements and finishes.

Design life of galvanized steel sections in common applications in buildings

Product application	Environmental condition	Design life / protective measures
Walls and floors in *warm frame* applications	No risk of water ingress or condensation	> 200 years G275* galvanizing
Roof structures (insulated)	Low risk of condensation	100 years G275 galvanizing
Roof structures (uninsulated)	Some risk of condensation	60 years G275 galvanizing
Purlins and side rails in metal cladding	Low risk of condensation; some dust and pollution	60 years G275 galvanizing
Infill external walls in multi-storey buildings	Warm frame and no risk of water ingress	100 years G275 galvanizing
Subframes to over-cladding panels	Low risk of water ingress; some risk of condensation	60 years G275 galvanizing

* G275 refers to the weight of standard zinc coating (275 g/m^2).

Recommendations are given on the detailing of light steel framing in *warm frame* applications in order to minimise the presence of moisture during the life of the building frame.

Durabilité des charpentes légères en acier utilisées dans les immeubles résidentiel

Resumé

La publication présente une synthèse des recherches réalisées sur la durabilité des profils, en acier galvanisé formés à froid, utilisés dans le secteur du bâtiment résidentiel. Elle passe en revue les rapports et publications relatifs à des recherches réalisées par Corus (anciennement British Steel), DETR, BRE, ECSC et le SCI concernant les produits en acier profilés à froid. De nouvelles données ont été également obtenues à partir de mesures réalisées dans des maisons et bâtiments résidentiels utilisant des composants légers en acier.

Les résultats obtenus avec des profils galvanisés, utilisés en tant qu'éléments de charpentes chaudes *sont excellents. L'étude montre que l'espérance de vie, calculée sur base de la perte d'épaisseur du revêtement en zinc, est supérieure à 200 ans, si la maintenance de l'enveloppe de l'immeuble est réalisée correctement. Une formule donnant la perte de zinc en fonction du temps, dans les endroits où les risques de condensation sont faibles, est donnée dans la publication.*

Le tableau ci-dessous résume l'espérance de vie des profils galvanisés pour les applications habituelles dans les bâtiments. Comme l'acier ne flue pas et ne présente pas de retrait sous charges, il ne contribue pas à la fissuration ou à la détérioration des éléments non structuraux ou de finition.

Durée de vie des éléments en acier galvanisé pour les applications habituelles dans les bâtiments

Application	Conditions environnementales	Durée de vie / mesures de protection
Parois et planchers dans des applications de type *charpente chaude*	Pas de risque d'entrée d'eau ou de condensation	> 200 ans Galvanisation G275*
Toitures (isolées)	Risque faible de condensation	100 ans Galvanisation G275
Toitures (non isolées)	Risque de condensation	60 ans Galvanisation G275
Pannes et lisses pour bardages et toitures en acier	Risque faible de condensation; poussières et pollutions éventuelles	60 ans Galvanisation G275
Pannes extérieures dans les immeubles multi-étagés	Charpente chaude et pas de risque d'entrée d'eau	100 ans Galvanisation G275
Cadres secondaires pour panneaux de sur-revêtement	Risque faible d'entrée d'eau; risque de condensation	60 ans Galvanisation G275

* G275 se réfère au poids d'une galvanisation standard (275 g/m^2).

Des recommandations sont données concernant les détails conseillés, dans les charpentes chaudes, afin d'éviter les risques d'humidité durant la durée de vie de la charpente.

Dauerhaftigkeit von leichten Stahltragwerken im Wohnungsbau

Zusammenfassung

Diese Publikation präsentiert eine Zusammenfassung von Forschungsergebnissen bezüglich der Dauerhaftigkeit von galvanisch verzinkten Kaltprofilen aus Stahl im Wohnungsbau. Sie gibt einen Überblick über Berichte und Veröffentlichungen früherer Projekte über Kaltprofile aus Stahl, die von Corus (früher British Steel), DETR, BRE, ECSC und SCI durchgeführt wurden. Auch neue Daten von Messungen an Häusern und ähnlichen Gebäuden aus leichten Stahlbauteilen wurden zusammengetragen.

Das Verhalten von galvanisch verzinkten Stahlbauteilen bei Verwendung innerhalb warmer Tragwerke *ist sehr gut. Die Studie zeigt, daß die vorhergesagte Lebensdauer unter Zugrundelegung des gemessenen Zinkverlusts über 200 Jahre beträgt, vorausgesetzt, daß die Gebäudehülle richtig unterhalten wird. Der Beweis für diese Schlußfolgerung basiert auf der Messung des Zinkverlusts leichter Stahltragwerke in verschiedenen Anwendungsfällen und an verschiedenen Orten. Eine Formel für den Zinkverlust in Abhängigkeit der Zeit in Gegenden mit geringem Risiko von Kondensation wird vorgestellt.*

Die folgende Tabelle faßt die erwartete Lebensdauer galvanisch verzinkter Stahlquerschnitte in üblichen Anwendungsfällen bei Gebäuden zusammen. Daß Stahl nicht schwindet, sich nicht verzieht oder unter Last kriecht, entstehen keine Risse oder Schäden an nichttragenden Elementen und Ausbauteilen.

Lebensdauer galvanisch verzinkter Stahlquerschnitte in üblichen Anwendungsfällen bei Gebäuden

Produktanwendung	Umgebungsbedingung	Lebensdauer / Schutzmaßnahmen
Wände und Decken in warmen Tragwerken	Kein Risiko für Wassereintritt oder Kondensation	> 200 Jahre G275* Verzinkung
Dächer (gedämmt)	geringes Kondensationsrisiko	100 Jahre G275 Verzinkung
Dächer (ungedämmt)	etwas Kondensationsrisiko	60 Jahre G275 Verzinkung
Pfetten und Wandprofile in Metallfassaden	geringes Kondensationsrisiko; etwas Staub u. Verschmutzung	60 Jahre G275 Verzinkung
Ausfachung in Außenwänden von Geschoßbauten	Warmes Tragwerk und kein Risiko für Wassereintritt	100 Jahre G275 Verzinkung
Unterkonstruktion für Fassaden	geringes Risiko für Wassereintratt etwas Kondensationsrisiko	60 Jahre G275 Verzinkung

* G275 bezieht sich auf das Gewicht der Zinkschicht (275 g/m^2).

Empfehlungen für Ausführungsdetails von Kaltprofilen in warmen Tragwerken werden gegeben, um das Risiko von Feuchtigkeitsbildung während der Lebensdauer des Tragwerks zu vermeiden.

Durabilità di sistemi strutturali leggeri in acciaio per edifici residenziali

Sommario

Questa pubblicazione presenta una sintesi dei risultati di ricerche condotte sulla durabilità di profili zincati in acciaio presso ! piegati a freddo. In dettaglio, sono presentati i documenti e le pubblicazioni di precedenti progetti sviluppati da Corus (originariamente British Steel), DETR, BRE, ECSC e da SCI su prodotti sagomati a freddo in acciaio. Sono stati riportati anche nuove informazioni relative a misurazioni effettuate in edifici ad uso residenziale o similare in cui vengono impiegate componenti strutturali leggere in acciaio.

Il comportamento di componenti realizzate in acciaio zincato (ossia rivestito di zinco) per le applicazioni relative alle pareti ventilate è ottimo. Lo studio condotto mostra che la predetta vita di progetto, basata sulla misura della perdita dello strato di zinco ricoprente l'acciaio, è superiore ai 200 anni nell'ipotesi che venga mantenuto l'inviluppo protettivo dell'edificio. L'evidenza di questa conclusione è basata sulla misura della perdita di zinco in telai leggeri in acciaio in varie applicazioni e in differenti posizioni. Viene anche presentata una formula per la predizione della perdita dello zinco nel tempo in zone a basso rischio di condensa.

La tabella proposta presenta in sintesi la vita di progetto attesa di sezioni zincate in acciaio in applicazioni per edifici. L'acciaio non si ritira, non si altera internamente o non mostra viscosità in presenza di carichi, e perciò non contribuisce al danneggiamento o al deterioramento degli elementi e delle finiture non strutturali.

Vita progettuale di profili in acciaio zincato impiegati in applicazioni comuni di edifici

Applicazione del prodotto	Condizioni ambientali	Vita di progetto / misure di protezione
Pareti e piani per applicazioni in pareti ventilate	Assenza di rischio di entrata d'acqua o di condensa	> 200 anni zincato G275*
Coperture (isolate)	Basso rischio di condensa	100 anni zincato G275
Coperture (non isolate)	Probabile rischio di condensa	60 anni zincato G275
Arcarecci e elementi perimetrali dei sistemi di tamponamento	Basso rischio di condensa, un certo livello di polvere e inquinamento	100 anni zincato G275
Pareti esterne piene in edifici intelaiati multipiano	Pareti ventilate e nessun rischio di infiltrazioni d'acqua	60 anni zincato G275
Sistemi intelaiati di sostegno ai tamponamenti	Basso rischio d'infiltrazioni d'acqua; qualche rischio di condensa	60 anni zincato G275

* G275 è riferito al peso del rivestimento usuale di zinco (275g/m^2).

Con riferimento alle sezioni sagomate a freddo in applicazioni per pareti ventilate sono inoltre fornite raccomandazioni sulle principali regole che consentono di evitare i rischi associati alla presenza di umidità durante la vita del sistema intelaiato.

Durabilidad de estructuras ligeras de acero en edificios de habitación

Resumen

Esta publicación presenta un resumen de los resultados de las investigaciones llevadas a cabo sobre la durabilidad de perfiles estructurales conformados en frío y galvanizados utilizados en viviendas. Se pasa revista a informes y publicaciones de proyectos previos llevados a cabo por Corus (antiguamente British Steel), DETR, BRE, ECSC y SCI sobre productos de acero conformados en frío. También se han recolectado nuevos datos a partir de medidas llevadas a cabo en viviendas y otros edificios semejantes que han usado piezas ligeras del acero.

El funcionamiento de componentes de acero galvanizado (con revestimiento de zinc) en estructuras en ambiente cálido es muy bueno. El estudio demuestra que la vida de proyecto predicha basada en la perdida medida del revestimiento de zinc, supera los 200 años siempre que le envoltura del edificio sea adecuadamente mantenida. La evidencia de esta aseveración radica en la medida de las pérdidas de zinc en estructuras ligeras de acero en diferentes emplazamientos y tipos estructurales. Se presenta una fórmula que da la pérdida de zinc en función del tiempo en zonas con bajo riesgo de condensación.

La tabla siguiente resume la vida de proyecto esperada en perfiles de acero galvanizado para aplicaciones corrientes en edificación. El acero no sufre retracciones, alabeos o fluencias en carga por lo que no contribuye a la fisuración o deterioro de los acabados y elementos no estructurales.

Vida de proyecto de perfiles galvanizados de acero para aplicaciones corrientes en edificación

Tipo de uso	Condiciones medioambientales	Vida de proyecto/ medidas de protección
Muros y suelos en estructuras en ambiente templado	Sin riesgo de condensaciones o humedad directa	> 200 años galvanización G275*
Techos (aislados)	Riesgo de condensación bajo	100 años galvanización G275
Techos (sin aislar)	Algún riesgo de condensación	60 años galvanización G275
Correas y angulares en revestimientos metálicos	Riesgo de condensación bajo; algo de polvo y contaminación	60 años galvanización G275
Muros de relleno externos en edificios de varias puertas	Estructura en ambiente templado sin riesgo de humedad directa	100 años galvanización G275
Subestructuras para paneles de sobre-revestimiento	Bajo riesgo de entrada de agua; algún riesgo de condensación	60 años galvanización G275

* El apelativo G275 se refiere al peso del revestimiento típico de zinc (275 g/m^2).

Se dan recomendaciones sobre los detalles de perfiles de acero conformados en frío en aplicaciones a estructuras en ambiente templado para evitar el riesgo de la presencia de humedad respecto a la vida de la estructura del edificio.

Livslängd hos bostäder i lättbyggnad med stål

Sammanfattning

Publikationen sammanfattar forskningsresultat med avseende på livslängden hos varmförzinkade tunnplåtsreglar i bostadshus. Publikationen inkluderar resultat från tidigare forskningsprojekt om tunnplåtsprodukter som utförts av Corus (tidigare British Steel), DETR, BRE, ECSC och SCI. Vidare redovisas nya mätresultat från bostadshus och liknande byggnader med tunnplåtsstomme.

Livslängden hos varmförzinkade stålkomponenter i en isolerad byggnadsdel där risk för kondensation inte föreligger är mycket lång. Studien visar att uppskattad livslängd, baserad på uppmätt zinkförlust på tunnplåtsreglar, är mer än 200 år, förutsatt att klimatskalet (isolerade byggnadsdelar) är väl underhållet. Beviset för denna slutsats är baserad på mätningar av zinkförlust på tunnplåtstommar i olika användningsområden och lägen. I publikationen presenteras en formel för bestämning zinkförlusten över tiden, i områden med låg risk för kondensation.

Tabellen nedan sammanfattar förväntad livslängd hos varmförzinkade stålreglar i konventionell användning i byggnader. Eftersom stålstommen inte krymper, vrider sig eller kryper vid belastning ger den inte bidrag till sprickbildning eller försämring av de icke bärande byggnadsdelarna och ytskikten, och bidrar därmed inte till att förkortad livslängd.

Livslängd för varmförzinkade stålreglar i olika applikationer i byggnader

Användningsområde	Förutsättningar	Livslängd/ rostskyddande lager
Isolerade väggar och golv	Ingen risk för inträngande vatten eller kondensation	> 200 år G275*
Tak (isolerade)	Låg risk för kondensation	100 år G275
Tak (oisolerade)	Viss risk för kondensation	60 år G275
Tunnplåtsprofiler i system för plåtfasader	Låg risk för kondensation; någon nedsmutsning kan förekomma	60 år G275
Utfackningsvägg i flervåningshus	Isolerad regelstomme och ingen risk för inträngande vatten föreligger	100 år G275
Stomme för upphängning av nya fasader vid renovering	Låg risk för inträngande vatten; någon risk för kondensation	60 år G275

* G275 betecknar vikten av standard zinkbeläggning (275 g/m^2).

Rekommendationer ges vad gäller detaljutformning av tunnplåtsreglar i isolerade byggnadsdelar i syfte att undvika risk för fukt över byggnadsstommens livstid.

1 INTRODUCTION

Galvanized steel has been used successfully for over 50 years in light steel framing and other components in housing and low-rise residential buildings in Australia, Japan, France, the USA and Canada. In the USA, the market for light steel framed construction is now over 100,000 houses a year, which is evidence of great user confidence and an excellent track record. In Australia, the market share for light steel framing in the housing sector is already over 15%.

In the UK, the current market for light steel framing is lower, but is increasing rapidly, and the same general principles of construction are used as in other countries where the market share is high. Modern light steel framing systems use sections that are cold formed from rolls of pre-galvanized (zinc coated) strip steel. The zinc coating is able to protect the steel much more reliably than paint coatings because it *passivates* the steel, and is resistant to damage and the effects of local moisture arising from condensation in transient conditions.

Historically, many steel housing *systems* were marketed in the UK between 1920 and 1970 [1], however the house building systems of the pre- and post-war period used painted hot rolled steel components, and were not insulated to modern standards. The performance of the earlier steel houses, which are now 30 to 70 years old, has generally been good despite some poor construction details employed when questions of building physics were less well understood.

Galvanized steel provides a much higher level of protection and, in modern building construction, the risk of moisture within the insulated building envelope is largely eliminated.

This publication reviews aspects relating to the durability of light steel framing in modern construction, and presents the results of surveys and case studies of the performance of galvanized steel in housing and related applications. Recommendations on the expected design life are given, with particular emphasis on the use of light steel framing in interior environments. Under normal circumstances, the light steel components within a *warm frame* are subject to only minor temperature and humidity fluctuations compared with the external conditions.

The durability of light steel and its coatings in a range of climatic and exposure conditions is the subject of continuing research both in the UK and internationally. Further data are being collected through exposure trials and monitoring of buildings in the UK, Finland, Portugal, Japan, Australia and the USA, and the present findings support the conclusions of this report.

1.1 Light steel framing in housing

The use of light steel framing in housing and residential buildings is a recognised growth area. Cold formed sections are the primary components of light steel framing, the sections being produced from pre-galvanized steel strip by processes known as cold rolling. Smaller components and other sections of varying shape can be produced by *press braking*.

The advantages of light steel framing include speed of on-site construction, achieved by pre-fabrication of the wall panels and their easy assembly on site. This creates a dry working environment for following trades, allowing the brickwork cladding and roof tiling to follow off the critical path. Optimised light steel framing systems have been developed that meet all the structural and building physics performance requirements of the Building Regulations.

Light steel frames are constructed using cold formed steel components, typically of C or Z section. The sections are joined using bolting, self-drilling self-tapping screws, rivetting, clinching, welding (in the factory), or new methods such as press joining. Any factory-produced welds are painted over with zinc-rich paint to maintain the required level of protection.

There are three basic residential steel framing assembly methods:

- stick built construction (site assembled)
- panelised systems (factory made and site assembled)
- pre-engineered modular or volumetric systems (factory made and assembled).

Most light steel framing systems in residential construction use wall panel construction, as illustrated in Figure 1.1. Typically, standard cold formed sections are used for all assembly methods. The C shape section is commonly used for the studs in walls and frames, while either C or Z sections are used for joists in internal floors. Decking panels have been used in composite ground floor construction.

Figure 1.1 Light steel framing in housing

The sections are usually rolled from pre-galvanized sheet steel that is typically 0.9 to 3.2 mm thick with a minimum G275 zinc coating (see Section 2.1). This thickness of zinc coating has adequate durability for internal *warm frame* applications but additional corrosion protection measures may be required for more aggressive external environments.

Most light steel framing systems have been assessed by the British Board of Agrément (BBA), based on a rigorous testing regime. In these BBA approvals, the frames are required to remain dry and reasonably airtight in the so-called *warm frame* construction envelope in all reasonable circumstances during the life of the building.

A general guide to the use of cold formed steel is given in the SCI publication *Building design using cold formed steel: An architect's guide*[2], and design advice is given in *Building design using cold formed steel sections: Construction detailing and practice*[3].

1.1.1 *Warm frame* construction

In *warm frame* construction, the cavity faces of an external wall frame will be sheathed and insulated, or insulated with a suitable board material (see Figure 1.2). This ensures that the light steel components are kept above a certain temperature, thus minimising the risk of interstitial condensation and avoiding pattern staining on the internal wall face. A breather membrane is recommended in exposed locations where driving rain may penetrate the outer skin and would otherwise wet the insulation layer [3].

Figure 1.2 Warm frame construction showing external insulation

In other cases, insulation may be placed between the wall studs, provided that there is sufficient insulation outside the studs to avoid cold bridging and therefore to avoid condensation on the studs. However, insulation to external walls positioned solely within the depth of the studs will not prevent interstitial condensation from forming on the stud members themselves.

1.1.2 Roofs in steel framed houses

Purpose-made light steel trusses have been marketed for many years. Typically, they comprise cold formed sections as flanges, with bent bars or tubes forming the bracing elements welded to the flanges. They can be designed for spans of 5 to 20 m (up to 30 m in special applications) and can be used for flat or slightly pitched roofs, or as long spanning floor joists.

The pitched or *Fink* roof truss is widely used in timber construction, and can be replicated in cold formed C or Z sections; however the more efficient use of steel is in the creation of *open-roof* systems for habitable use.

There are two generic forms of roof design:

- a *cold roof*, in which the roof acts only as a weathertight barrier
- a *warm roof*, in which the roof is insulated, so that the space under the roof is relatively warm.

1.1.3 Floors

Steel floor joists of C or Z section may be used in place of timber joists in housing and other masonry buildings. The joists may be built into walls or supported on traditional joist hangers. Thicker cold formed sections may also be used to replace light hot rolled steel sections as secondary members in frames.

Internal floors are in the warm internal environment, however there may be applications where this is not the case, for example:

- suspended ground floors
- flat roof structures or over-roofing of existing buildings
- joists built into solid masonry walls.

In these applications, where steel can be exposed to moisture over an extended period, care should be taken to ensure adequate ventilation. Thicker galvanizing or some additional form of protection may be required.

1.1.4 Ground floors

Suspended composite ground floors have been used successfully in demonstration buildings that utilise galvanized steel decking together with an in situ concrete slab. The degree of exposure is mild, provided that good ventilation is provided in the void beneath the floor and contact with soil is avoided.

Under-floor insulation is more economic than insulation placed above, and makes the floor part of the *warm frame*. It also acts as an added protection barrier to prevent moist air reaching the galvanized surface.

1.2 Types of galvanized coating

The standard form of corrosion protection for cold formed steel sections is the continuous dip zinc coating applied as a pre-coat to the roll of strip steel from which the sections are formed. Galvanized steel strip is now supplied to the specification in BS EN 10147 [4], which has replaced BS 2989 [5].

The zinc adheres to the steel substrate and deforms around the bends during forming, even in complex section shapes, without cracking or becoming detached. Because of this, galvanizing has become the standard method for corrosion protection of cold formed steel in a wide range of applications not subject to direct weathering or exposed conditions. A brief review of the action of the zinc coating is presented in Section 2.

Galvanized strip steel is produced with a standard G275 coating, corresponding to 275 grams of zinc per square metre summed over both faces of the steel strip. This corresponds to approximately 0.02 mm overall thickness of zinc per face. Other coating thicknesses are available for special applications.

Hot dip galvanizing after forming is applied to complex steel fabrications and the coating will now comply with BS EN ISO 1461:1999, which has replaced BS 729 [6]. More guidance on this technology is available from the Galvanizers Association (see page 50).

A new standard, BS EN ISO 14713 [7], provides information on zinc and aluminium coatings and their expected design lives in different environments.

Zinc-aluminium coatings are also available, and are used in some countries such as Australia, particularly for roofing and cladding applications.

1.3 Performance of galvanized steel products

Galvanized steel has been used for over 50 years in a wide range of building components in the UK, even if its use in primary structural members is relatively new. The applications that are inside the building envelope have given satisfactory performance, showing that durability is not a concern. Good examples are:

- window lintels supporting brickwork
- joist hangers for timber floors
- connecting plates for timber trusses.

In industrial buildings, the satisfactory performance of galvanized steel purlins and side rails, which are often in a variable internal climate, leads to the conclusion that the standard galvanizing thickness is adequate for most applications within buildings.

In more aggressive locations, such as externally, or with poor quality brickwork, rainwater can gradually remove the beneficial effect of the galvanizing layer (see Section 2.4). Therefore, it is concluded that galvanized steel is **not** recommended for long life applications in areas subject to:

- continuous wetting and drying
- running rainwater over the surface
- leakage from service pipes etc.
- corrosive or acidic materials or polluted atmospheres.

Components and members using galvanized steel should be located within the building envelope in such a way that potentially aggressive locations are avoided or minimised. Good practice is addressed in a recent SCI publication *Building design using cold formed steel sections: Construction detailing and practice*[3].

Section 3 presents a review of case studies into the performance of galvanized steel in residential buildings, and Section 4 identifies the conditions where control of condensation or other moisture contact is necessary in order to ensure long-term durability of the zinc coating.

1.4 Other durability benefits of steel

In addition to the durability of the galvanized coating, it may be observed that the good performance of buildings using these light steel components is enhanced because:

- steel does not shrink, warp or change its shape
- steel does not creep under load
- steel has properties that remain constant over its life
- galvanized steel is unaffected by a flood or water overflow (provided that this is not a frequent occurrence)
- galvanized steel does not rot or deteriorate
- any local damage can be identified and rectified
- steel is resistant to local damage, particularly on site
- steel is non-combustible and fire resistant
- insect infestation is not a problem
- steel is of reliable and high uniform quality
- steel is not affected adversely by normal temperature ranges
- there are no nails to pop out, as in timber construction.

These properties are all aspects of durability and maintenance-free construction. Particularly important to the owner and builder is the reduced number of *call-backs* in light steel framing that would otherwise be necessary to rectify cracking caused by shrinkage and other movement of more traditional materials.

2 GALVANIZING AS CORROSION PROTECTION FOR STEEL

Steel is one of the most important structural materials available to specifiers, and various protection measures have been developed for its use in different exposure conditions. In external environments, the surface of bare carbon steel is unstable, reacting with air and airborne pollutants to form the complex series of oxides generically known as *rust*. In dry, warm environments this process does not occur and no protection is required. For example, most hot rolled steelwork within multi-storey buildings is unprotected because of the low risk of corrosion, as evidenced by over 70 years of excellent performance since the 1920s.

In exposed environments, some form of protection against corrosion is required. The main forms of protection are:

C **encapsulation** ! where a coherent barrier is used to exclude corrosive agencies from the surface

C **sacrificial** ! where another metal, which corrodes preferentially to steel, is used in proximity to the surface.

The use of metallic zinc (in galvanizing, sprayed metal coatings, plating, sherardising, zinc-rich paints, and cathodic protection) as corrosion protection may call on one or both of these mechanisms. Hot dip galvanizing provides both forms of protection.

2.1 The hot dip galvanizing process

Hot dip galvanizing involves dipping steel in almost pure molten zinc. The zinc and steel react to form a series of zinc-iron alloy layers bonded metallurgically to the steel. When the steel is lifted from the bath, molten zinc on the surface of the bonded alloy coating solidifies and becomes part of the coating itself.

Because of the rather casual use of the term *galvanizing* within the building industry, it is not always appreciated that immersion of steel in molten zinc can create various products. Differing steels, different zinc alloys and variations in the process may be used to alter the character of the final coating.

Standard hot dip batch galvanizing (dipping each fabricated item separately into the bath) generally produces a series of zinc-iron alloy layers topped with a layer of pure zinc.

In contrast, continuous galvanizing onto steel coil tends to produce only a very thin zinc-iron alloy layer with a (relatively) thick pure zinc top layer, because of the speed at which the steel coil passes through the bath. The total film thickness is, therefore, much less than with the batch process. Continuous zinc coating of the steel coil is controlled carefully to produce a range of coating weights for different specifications of corrosion protection.

In the UK, the working standard has been 275 g/m² (i.e. a surface thickness of about 20 microns). This grade was formerly used in BS 2989 [5] and has now been incorporated within BS EN 10142[8] and BS EN 10147[4]. The coatings are thinner than those formerly specified in BS 729 [6] because research shows that the corrosion resistance is satisfactory for most internal building applications.

The technology of coating has improved, and there are many sources of continuous zinc-coated steel strip. Corus's product name *Galvatite* will be known to many specifiers.

In the field of continuous metal coatings, various zinc-aluminium alloys are available as an alternative to pure zinc coatings. One very well-known product is the original Bethlehem Steel formulation 55% aluminium–45% zinc, which is available as coated steel coil from several licensees.

Post-galvanizing treatments may be offered to protect the zinc coating during storage. These treatments include chromate passivation to suppress the development of white zinc corrosion products that can form in continuously wet conditions, such as when water is trapped between the sheets. A thin film of mineral oil is applied to the surface for the same purpose. Oil must be removed if the product is to receive further treatment such as painting or welding.

2.2 Performance of galvanized coatings

Zinc coatings provide a barrier that prevents oxygen, moisture and other atmospheric pollutants from reaching the steel. Furthermore, zinc is a reactive metal and, on exposure to the atmosphere, a complex mixture of zinc compounds forms readily on a galvanized surface. Because many of the products formed (e.g. zinc hydroxide or *white rust*) are at least partially soluble in water, the zinc is consumed over a period of time in any damp location. The loss of zinc is accelerated in situations where the galvanized surface is exposed to the atmosphere and to water running over the surface.

In more benign exposures, an initial layer of zinc hydroxide often changes to a hard, stable layer of zinc carbonate by the absorption of carbon dioxide, and this provides a further barrier layer to any further loss of zinc from beneath. The consumption of zinc, and hence the life of zinc-coated steels, can be calculated with reasonable accuracy for specific environments from research data. This loss of zinc with time is part of its protective mechanism, and should not be considered as a failure of the protective system.

Galvanizing has the advantage that, when the encapsulation is breached, for example at cut edges or drilled holes, or when the zinc has been eroded away locally, significant corrosion of the steel substrate will not necessarily occur. This is because zinc in close proximity to the exposed steel will still corrode preferentially, acting as a consumable anode in an electrochemical cell (i.e. it protects the steel cathodically). The use of a sacrificial metallic layer is known as galvanic action. Only when the distance between the zinc and steel is too great will the steel begin to corrode. The galvanic series of metals is shown in Table 2.1.

Table 2.1 Galvanic series of metals

Anodic:	Magnesium	(Electronegative)
	Zinc	
	Aluminium	
	Cadmium	
	Iron or steel	
	Stainless steels	
	Lead	
	Tin	
Cathodic:	Copper	(Electropositive)

The more anodic (electronegative) metal will corrode preferentially to the more cathodic metal (in the presence of water and oxygen). Therefore common coating metals such as zinc and aluminium will protect the steel substrate against corrosion. Conversely, stainless steel or more electropositive metals may lead to preferential corrosion of mild steel, if directly connected and subject to prolonged moisture.

2.2.1 Loss of thickness of zinc with time

Although the hot dip galvanizing process has not been reformulated, the expected product lifetime in external atmospheres has almost doubled over the last twenty years in the UK. This is a consequence of improved air quality, as in most European countries. This has enabled hot dip galvanized coatings to protect steel for longer periods, and newly manufactured components are given a much longer life expectancy than would have been predicted 20 years ago, while old coatings are expected to exceed the original predicted life expectancy.

All hot dip galvanized products benefit from the European environmental regulations intended to decrease the level of airborne sulphur dioxide (SO_2), the main cause of *acid rain*. Because the effective life of galvanized coatings is inversely proportional to the levels of airborne SO_2, their life expectancy has increased as the pollution has decreased. Given that hot dip galvanizing is unaffected by ultra-violet (UV) light, it is also able to outperform other coating systems in countries where UV levels are high[9].

In a mathematical model designed to investigate the relationship between SO_2 levels and the reduction in thickness of zinc, lowering the SO_2 concentration in the air by 1 mg/m^3 led to a reduction in loss of coating thickness of exposed zinc of about 0.2 g zinc/m^2, or 0.03 mm, per year[9]. In observations in Stockholm since 1978, the improvement in the performance of zinc has corresponded to the strong downward change of the concentration of SO_2 in the air (see Figure 2.1).

Maps published by the Agricultural Development Advisory Service show the corrosivity of the atmosphere across the UK and indicate that the expected lifetime of a fully exposed 85 micron galvanized coating has increased from 24 to 34 years in non-coastal environments.

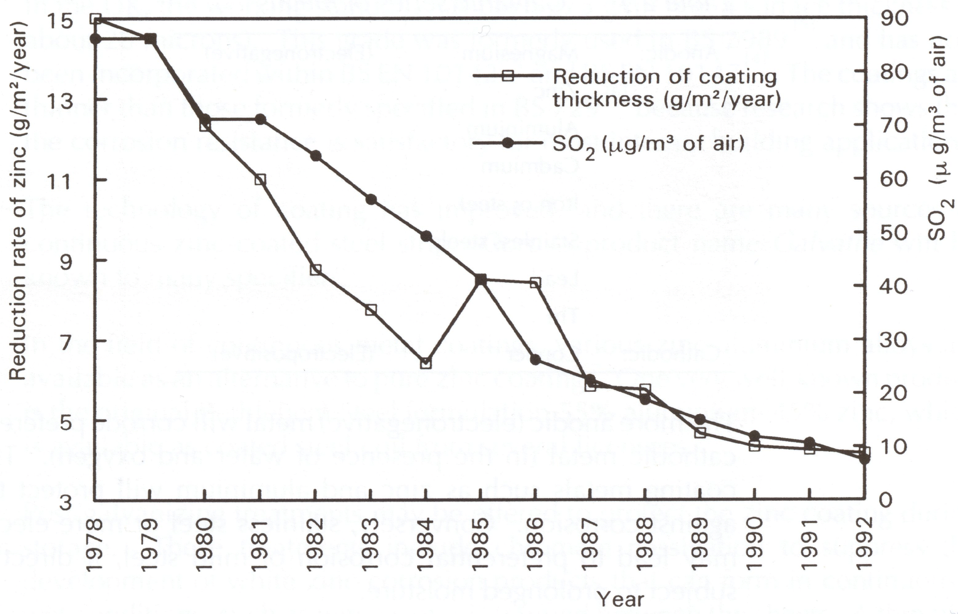

Figure 2.1 Graph showing SO_2 levels and rate of reduction of zinc coating thickness in Stockholm since 1978

The approximate performance of zinc coatings in different environments is shown in Table 2.2, which is taken from a discussion document[9] for a proposed new European Standard for hot dip galvanizing. The lifetime of zinc coatings has improved, and recent work suggests that these figures are very conservative[10].

Table 2.2 Performance of zinc coatings in different environments

	Environment		Corrosivity of environment	Average reduction in coating thickness (microns/year)
C1	Interior:	dry	Very low	0.1
C2	Interior: Exterior:	occasional condensation inland and rural	Low	0.1 - 0.7
C3	Interior: Exterior:	high humidity, some air pollution industrial and urban inland or mild coastal	Medium	0.7 - 2.0
C4	Interior: Exterior:	swimming pools, chemical plants etc. industrial inland or urban coastal (chloride-rich environment)	High	2.0 - 4.0
C5	Exterior:	industrial with high humidity or high salinity coastal	Very high	4.0 - 8.0

The relationship between levels of airborne SO_2 and the life expectancy of exposed galvanized coatings is best understood in terms of the reaction by which zinc protects steel.

The zinc galvanized coating attains its anti-corrosion characteristic because a protective layer forms at its surface. This protective layer, or patina (see Figure 2.2), consists of a mixture of zinc compounds including zinc carbonate, zinc oxide and zinc hydroxide. Environmental factors dictate which of these compounds are formed.

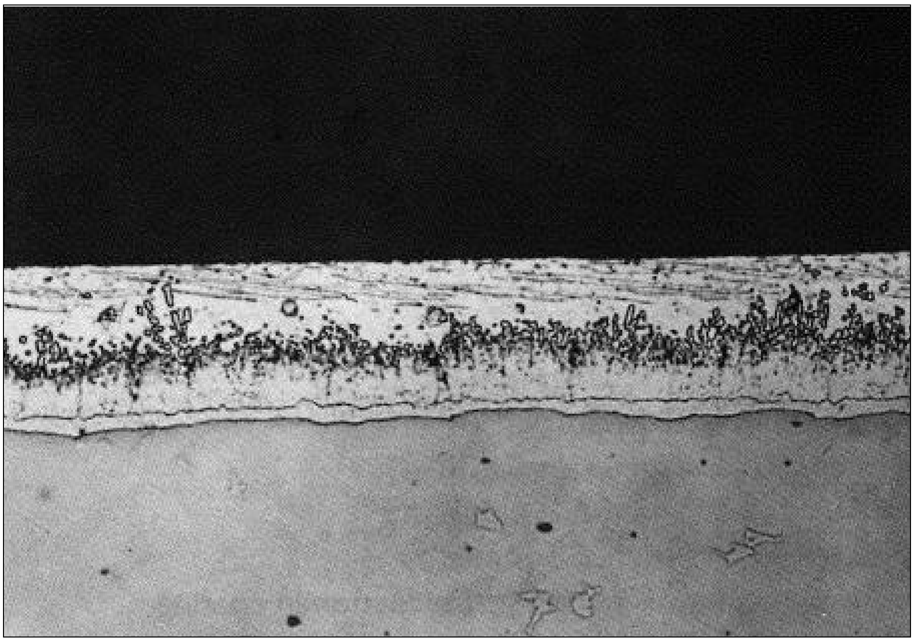

Figure 2.2 Typical micrograph of hot dip galvanized coating

In dry air, a film of zinc oxide is initially formed by the influence of oxygen in the atmosphere, but this is soon converted to zinc hydroxide, zinc carbonate and other zinc compounds by water, carbon dioxide and chemical impurities present in the atmosphere. The patina of zinc carbonate, when fully formed across the entire surface, has excellent anti-corrosion qualities that are long-lasting because rainwater cannot easily dissolve the zinc compound. However, if SO_2 is present in the atmosphere when the patina is forming, zinc sulphate will form along with the zinc carbonate. The zinc sulphate is more soluble and thus significantly more susceptible to the effects of rainwater. The rainwater gradually reduces the coating and its anti-corrosion abilities.

Falling levels of SO_2 have reduced the rate of build-up of zinc sulphates in the protective patina. The consequent improved resistance to corrosion leads to a marked increase in the lifetime of galvanized coatings. Further reductions in SO_2 levels are anticipated over the next decade, with a commensurate increase in life expectancy for galvanized coatings [9].

2.2.2 *White rust* on galvanized steel sections

White rust is a corrosion product of zinc formed from hydrated zinc carbonate/ zinc hyroxide under specific conditions of exposure. White rust cannot be seen until the steel is dry, when it appears as a white film.

Circumstances where white rust may occur are:

- Ingress of water between the adjacent surfaces in a stack of galvanized steel sheets or components during transport or storage.
- Condensation within a stack of sheets or components caused by rapid changes in temperature.

- Condensation from the drying out of new buildings or from the laying and drying out of a wet concrete screed.
- The combined effect of weather and site dust on the components of a building frame prior to application of the weather skin.
- The combined effects of weather and site dust on roof decking prior to the application of insulation and weatherproofing.

Although the white rust may be found over a large area, it does not necessarily mean that the steel has suffered corrosion. White rust does not usually indicate a serious degradation of the zinc coating or that the product life has reduced. It is acceptable to ignore thin films of white rust present in normal environments unless the steel surface needs to be painted. Removal of white rust will accelerate the loss of zinc. However, white rust should not be ignored in severe environments, where other corrosion is evident or where there are heavy deposits of white rust, which indicates the continual presence of moisture. Measures to control the degree of moisture exposure and white rust are given in Table 4.2 of Section 4.7.

To inhibit the formation of white rust, a chromated layer is used as the standard coated product in the UK (see Section 3.2.2).

2.3 Forming sections after galvanizing

Thin steel sections are generally formed by cold rolling during which the steel section is formed continuously by bending the galvanized steel strip through a series of rolls. Complex sections can be created by forming multiple bends and stiffeners. The zinc coating is able to deform and adhere to the steel surface during the forming process, although the thickness of zinc may reduce slightly as the steel stretches. Therefore, the galvanic action of the zinc coating is unaffected.

The sections are cut to length, and holes are punched for bolts and for services. The action of punching and shearing causes some of the zinc coating to spread over the cut surfaces. However, the main source of corrosion protection to cut edges arises from the galvanic action of the zinc adjacent to the cut edge, and there is no evidence that higher levels of corrosion occur at cut edges in practice. Furthermore, the edges or ends of the members are not usually highly stressed and are unlikely to be the critical parts of the component or member. Screws or bolts do not affect the performance of the steel, provided that they are also protected by galvanizing or are made from a suitable metal.

2.4 Factors affecting durability in the building envelope

When considering the durability of galvanized steel sections, it is necessary to consider two main criteria: the duration of wetness, and the general atmospheric or exposure condition. The shorter the time of wetness and the drier the atmosphere, the better. The rate of zinc loss in an internal environment is less than 10% of that in an external environment because of the drier indoor conditions. However, if the building envelope is of poor quality, the time of wetness can be greater, due to condensation and possible external water ingress. Transient moist conditions due to condensation are much less critical than the case of water washing over the zinc surface because zinc hydroxide, which is produced by contact with moisture, is soluble and can be washed away.

Good building practice, thermal insulation and proper ventilation ensure that the design of modern houses conforms to a warm dry environment, even though humidity is created by the occupants or activities inside.

There is long experience of using galvanized steel in housing but even within the building envelope, exposure conditions can vary considerably. Often in older buildings, the practices and materials used were such that the galvanized steel is more at risk than in modern buildings. The following applications demonstrate the importance of understanding the risk of moisture or chemical attack, particularly for steel components located in the building envelope.

2.4.1 Galvanized steel wall ties

Wall ties are used to tie two leaves of masonry walls together in a cavity wall construction. Wall ties, such as butterfly ties, were made of galvanized steel until recently, when stainless steel wire became commonly accepted. The subject of wall ties is mentioned here because it is a well documented example of the use of galvanized steel in an aggressive external wall environment where careful investigation has led to a thorough understanding of the causes of corrosion and of practical solutions.

It has been found that excessive corrosion of galvanized steel ties can be caused by the high sulphate content of some brick/mortar types, which, when coupled with moisture penetration into the outer leaf, causes an acidic attack. The consequent corrosion products can produce enough expansion to crack the masonry or the mortar joints with the heavier forms of butterfly tie.

As a result of surveys carried out by the Building Research Establishment in the late 1970s and the subsequent interpretation of data, new design curves were developed and it was shown that the thickness of zinc coating on wall ties needed to be increased to give the required notional 60 years' life. Alternatively, a secondary bitumen paint coating could be applied to the standard lower thickness coating. BS 1243[11] was consequently revised in 1981.

The database from that research is given in BRE Digest 401 [12] (also in IP 16/88 and IP 12/90). The subject of wall ties is raised here because the research provides evidence of poor durability in the outer leaf of walls, where the quality of the brickwork and mortar is poor. Anecdotal evidence from many hundreds of thousands of buildings shows that galvanized wall ties have performed well in cases where the brickwork is of good quality. Many of these buildings with cavity walls are now over 60 years old. The conditions in the inner leaf of the wall are more relevant, and here the BRE data show much less corrosion risk.

2.4.2 Galvanized steel lintels

Most lintels used in modern housing are made of galvanized steel, and this high market share has been achieved because of their ease of handling, long span capability, wide range of use in various applications, and their good long-term durability. Lintels are protected from direct moisture by the damp proof course placed above the lintel. Even so, the environmental conditions in a cavity wall are much more severe than in internal applications.

Lintels are fabricated and are often complex components with many cut edges and welds. After fabrication, every surface, cut, edge and weld is treated to ensure that it is fully protected. This post-galvanizing process creates a build-up of zinc protection at the most vulnerable points (edges etc.), which are susceptible to damage on site and would otherwise be the least protected. The specification for post-galvanizing is given in BS EN ISO 1461. Furthermore, BS 5977-2: Tables 1 and 2 give specific requirements for the protection of steel lintels [13].

The service life of the lintels will be more than 60 years when they are used with a flexible damp proof course and when the environmental conditions are as normally experienced in housing and residential buildings.

2.4.3 Galvanized steel joist hangers

Joist hangers are used to support timber floor joists, and are made using galvanized steel in accordance with BS 6178, which specifies a post-galvanized coating to comply with BS 729 [6]. Joist hangers have been used for many years in many types of building with no recorded poor performance, despite being bedded into the inner leaf of a cavity wall.

2.4.4 Connector plates to timber trusses

Connector plates to timber trusses have used galvanized steel for over 40 years. So-called *gang nail* trusses have performed well when sitting on the internal leaf of cavity walls, even when exposed to the variable atmospheric conditions in uninsulated lofts. The chemicals used in treating timber trusses do not have an adverse effect on the life of the steel.

2.4.5 Purlins and side rails

Galvanized steel sections are used as purlins and side rails to support metallic cladding in industrial buildings. Here, the performance in often dirty, humid environments has been good since these components came into service over 30 years ago. For example, in Corus's steelworks in Port Talbot, galvanized steel purlins were installed in 1967 and have performed satisfactorily without maintenance.

2.4.6 Light steel framing

As described in Section 1.1, modern light steel framing differs considerably from the previous uses of galvanized steel because the frame components are entirely *internal* to the building envelope. The *warm frame* is free from condensation, except possibly in extreme or transient conditions. The case studies in Section 3 review the data on the performance of light steel framing in service.

2.5 Design life of galvanized steel

The design life of a galvanized steel component comprises the *life* of the protection system plus that of the underlying steel. The design life of the protection system could be defined as the time period to the first major maintenance of the coating, when recoating or some other treatment is required to restore the total effectiveness of the protection. If there is no maintenance at this time, the coating would continue to deteriorate and the underlying steel start to corrode, eventually leading to serviceability problems (such as increased deflections). The design life does **not** represent structural failure of the component, and there will be a considerable margin between the design life and potential failure.

Two categories of use may be defined that influence the requirements for design life:

- Category A: concealment or encapsulation of components so that they cannot be inspected regularly.
- Category B: exposure of components so that they can be inspected readily, such as by removal of inspection panels or trapdoors etc.

Examples of Category A are wall frames, window lintels, wall ties and possibly ground floors. Examples of Category B are roof trusses, purlins, internal floors and external elements such as lighting poles.

The required design life depends on the conditions of use, as there should be a greater reserve of life for components that cannot be inspected and therefore cannot be assured for recoating, repair or replacement. Typically for residential buildings, the required design life is 60 years, representing a sensible time to major maintenance of the primary components.

In the context of galvanized steel, the definition of the actual design life depends on the degree of loss of zinc from the surface. The rate of zinc loss is unlikely to be uniform, and experience shows that some surface rusting may appear when an average of 50% of the original weight of zinc coating has been lost, i.e. the zinc loss is generally uneven. However, large scale surface rusting does not occur until most (say 80%) of the zinc has been lost; the subsequent life of the substrate will depend on the exposure environment.

To cater for this variability, a general basis of evaluation must be conservative, and the design life may be defined as a function of the conditions of use:

Category A: when 50% of the weight of zinc has been lost (which for G275 coating is 137 g/m^2).

Category B: when 80% of the weight of zinc has been lost (which for G275 coating is 220 g/m^2).

This is then consistent with other coated light steel products, such as roof sheeting, where the design life is related to the performance of the coating rather than the steel substrate. Therefore, in Category A, there is an implied factor of safety of 2 in terms of complete loss of zinc and failure of the component. In Category B, the factor of safety is 1.25.

Furthermore, when the design life of a component is predicted from the results of research on a small number of test specimens, it is necessary to make some allowance for the statistical possibility of a more severe loss of zinc in certain other locations. This is taken into account when interpreting the test results reported in Section 3.8.

This evaluation also assumes that the external envelope of the building is maintained and does not deteriorate, so that the environmental conditions do not change over the design life. The approach is conservative and gives a considerable margin (in time) between the design life and any serviceability problems.

2.6 Structural significance of the components

The relative importance of different types of component may be defined by their structural significance, which is important in establishing a protection strategy. For example, a heavily loaded column, or a tension-tie member that supports a large canopy or floor, is of high importance because of the severe consequences of failure. Also, in these members, approximately equal stresses exist over their length. A bending member may not be as critical because it is only the mid-span area that is heavily stressed, and the support zone (where the member is most exposed to corrosion) is less highly stressed as shear forces are relatively low in lightweight floors.

Components such as joist hangers are important because they support the floor, although loss of one joist hanger does not represent failure of the whole floor. Similarly, the members in light steel wall panels have a high degree of load sharing and *redundancy* due to their multiple interconnections; these structures are therefore *robust* to impact and damage.

A hierarchy of components may be established on the basis of:

- ease of inspection and repair (see previous section)
- structural significance.

Although it is not definitive, the list in Table 2.3 defines the general importance of the component, which should inform the protection strategy and maintenance regime. The most important members should be considered in Category A (in Section 2.5) whereas less important members or components may be considered in Category B.

Table 2.3 Hierarchy of importance in terms of durability

Column (heavily loaded)	
v Concealed tension-tie (e.g. in truss)	
Beam (supporting a floor)	
Exposed tension-tie (e.g. canopy)	
Bracing (at ground floor level)	
Wall panel (load bearing)	
Lintel above opening	
Joist hanger	
Floor joists	
Floor decking (internal)	Increasing importance
Roof purlin	
Connector plate (e.g. in truss)	
Wall ties	
Wall panel (non-load bearing)	
Side rails (for cladding)	
Roof or wall sheeting	
Noggins or straps	
Guttering and pipes	
Street architecture	

3 CASE STUDIES

The following case studies present information on the long-term performance of galvanized steel sections in various examples in which measurements of zinc loss have been made. The findings of a survey into the performance of the earlier use of steel in housing are given in Section 3.1 for additional background.

3.1 Building Research Establishment survey on older steel framed and steel clad housing

As an example of the historic background, an extensive survey of older steel framed and steel clad housing stock in the UK was undertaken by the Building Research Establishment (BRE) and is published in a series of individual reports together with an overview [1]. As noted earlier, these frames used hot rolled steel components with paint or bitumen coatings, and were often exposed to moisture as a result of the construction details employed and the insufficient insulation to meet modern standards.

The conclusion of this survey was that, although certain points in the steelwork were vulnerable to moisture, most of the corrosion found was superficial. Even though the level of protection afforded to steelwork was less than would be considered good practice today, it was concluded that most steel houses of the 1930-1970 period would continue to perform well for the foreseeable future. Advances in corrosion protection methods developed for steel over the past three decades have led to much improved quality and durability when combined with modern construction techniques.

3.2 Case 1: Environmental and performance monitoring of modern steel framed housing

The Department of the Environment sponsored a three year corrosion and environmental monitoring exercise in fifteen houses in Manchester, London and South Wales [10]. Galvanized steel test panels were exposed at opposite ends of each (unheated) house loft and were exposed to the atmosphere. The zinc corrosion rate was measured together with relative humidity, temperature and the time-of-wetness of any condensation. In addition, some laboratory experiments tested galvanized steel that was freely exposed to mortar and gypsum plaster in accelerated corrosion test environments.

The results showed that there was no significant difference in relative humidity or temperature values at the three geographical locations. Within a given roof space there was generally no significant difference between opposite sides of the loft, although occasionally relative humidity was affected by localised heating effects where, say, warm air escaped into the loft from a heated room below. Data-logging indicated that conditions that may lead to condensation can exist in roof spaces up to 21% of the time averaged over a year. Only one cavity wall was monitored, but it showed that conditions that may lead to condensation can exist for up to 16% of an average year. This result is consistent with that identified separately by the BRE (Scottish Laboratory) in cavity wall measurements.

3.2.1 Exposure conditions

The following data are taken from *Durability of galvanized steel building components in domestic housing*[10]. The average weight loss measured over a three-year period in a loft environment is given in Table 3.1. The average rate of zinc loss per year may be expressed as the total weight loss divided by the time period. For these data, the average rate of zinc loss was approximately 0.3 g/m²/year. Chromated galvanized steel was found to have a slightly lower rate of zinc loss than non-chromated galvanized steel. The data are subject to some variability because the specimens were removed and measured but were not replaced. There could therefore be some variation in exposure conditions and surface characteristics among the specimens (see Section 3.8).

Table 3.1 Average weight loss (g/m^2) for exposed specimens in a loft environment (after one, two and three years)

Materials	Number of years		
	1	2	3
Non-chromated galvanized steel	0.44	0.75	0.71
Chromated galvanized steel	0.28	0.69	0.47
Electro-galvanized steel	0.75	1.26	1.24
Mild steel (unprotected)	2.60	5.70	7

No significant difference was found between the corrosion rate of galvanized steel panels exposed at the north or south sides of each loft, and no significant difference was found in the corrosion rate of the panels in the three geographical areas.

For comparison, the equivalent uncoated mild steel specimens stored in the same locations lost weight at a rate of approximately 2.5 g/m^2/year (or 0.03 mm thickness of steel per year).

3.2.2 Laboratory tests

In the laboratory tests, the performance of galvanized steel in contact with gypsum plaster was evaluated, and it was found that, in conditions of prolonged high humidity, some loss of zinc occurred, which caused staining of the plaster. No staining occurred when the wet plaster was allowed to dry in a ventilated room. Plasterboard does not affect the zinc layer because it has relatively low moisture content and a paper surface that prevents any build up of moisture at the point of contact with the steel section.

3.2.3 Interpretation of zinc loss

From the results of these studies, the zinc weight loss (g/m^2) for galvanized steel exposed over a three-year period was found by linear regression analysis to follow a relationship of the form:

$$\text{weight loss} = a(\text{time})^b \quad (1)$$

where time is measured in years.

A difference in performance was observed between chromated and non-chromated zinc specimens (a chromate layer is the standard product in the UK).

The value of *b* was found to be 0.64, indicating that the rate of zinc loss decreases with time. This occurs because the protective oxide film that forms on the zinc surface in dry conditions reduces the exposure of the zinc. The line of best fit along the 95% probability line gives the value of *a* = 1.0, or approximately 2 × the mean of the data (see Figure 3.1). The expression becomes:

$$\text{weight loss} = 1.0\ (\text{time})^{0.64} \qquad (2)$$

Based on these data, for the 98% probability level, the constant *a* is 1.5.

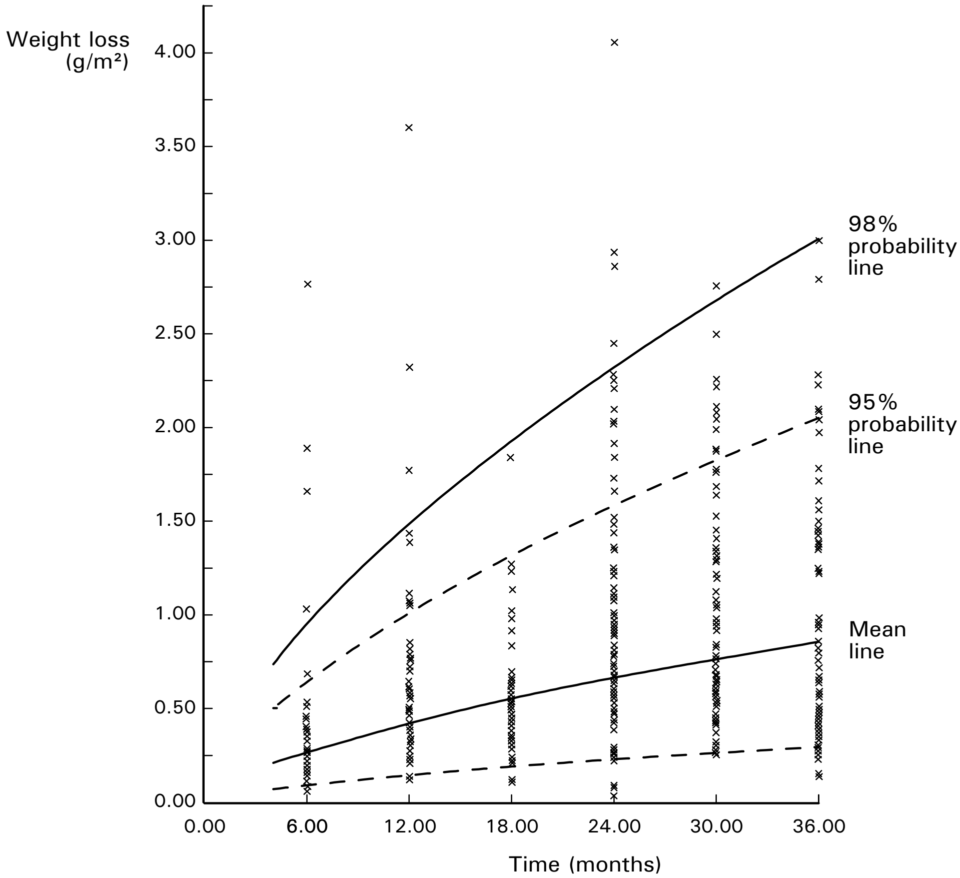

Figure 3.1 Zinc weight loss with time for freely exposed hot dip galvanized steel specimens

3.3 Case 2: Environmental and performance monitoring of the PMF steel framed building at Ullenwood

The residential building illustrated in Figure 3.2 was monitored to gain more data on in-service performance. This building is situated at the National Star Centre for disabled persons at Ullenwood near Cheltenham, and was one of the first light steel framing systems constructed by PMF in 1982. Areas investigated were the environmental conditions in the wall cavity, the loft and below the suspended ground floor[14]. The loft was monitored in the south corner, north corner, near the water tank and at the centre near the flue. The exercise included the measurement of rate of weight loss on galvanized steel and mild steel test coupons positioned at various locations, which were removed annually and weighed over the five-year project period[14].

Figure 3.2 Steel framed building for disabled persons at Ullenwood

Daily conditions were found to fluctuate over a wide range, to the point that there was some risk of condensation despite ventilation of the cavity space, roof and substructure. The study did not examine the time over which condensation occurred but concentrated on overall measurements of the performance of the galvanized steel wall-frames.

In the wall space and loft, the galvanized steel suffered very little weight loss, as shown in Table 3.2. The annual weight loss on the galvanized steel specimens was extremely low (0.2 g/m^2) compared with the mild steel specimens (1.26 and 1.62 g/m^2 in wall space and loft respectively) despite the wide fluctuations in temperature and relative humidity in these locations.

Table 3.2 Results of measurements on galvanized steel coupons installed in the wall space and loft of the Ullenwood building

Location	Time (months)	Measured zinc loss (g/m^2)	Annual zinc loss (g/m^2/year)
Wall space	6	0.09	0.18
	12	0.27	0.26
	18	0.3	0.2
	24	0.41	0.2
	60	1.2	0.24
Loft space	6	0.09	0.18
	12	0.19	0.19
	18	0.32	0.21
	24	0.29	0.15
	48	0.55	0.14
	60	0.59	0.12

Rate of zinc loss is averaged over the exposure time.

Over the five-year study period, the annual rate of zinc loss was approximately uniform. In February 1996 (after 14 years), the building was inspected and internal plasterboard panels were removed. Only slight tarnishing (i.e. loss of normal bright appearance as in Figure 3.3) was observed. In situ measurements were taken of the standard galvanizing on the wall studs, and could not detect any significant loss of the zinc coating. The rate of zinc loss is therefore negligible and is considered to correspond to a long-term rate of zinc loss of no more than 0.2 g/m^2/year.

The measurements taken of the specimens under the ground floor were affected by their proximity to an air brick in the external cladding. The rate of zinc loss after five years was 1.22 g/m^2/year. The conditions under the ground floor are not as severe as external conditions, but clearly the galvanized steel is exposed to moisture over a longer period than in *warm frame* applications. The exposure can be reduced by insulation or a membrane below the floor.

Figure 3.3 Wall panel removed, showing no trace of corrosion on the members after 15 years (the connections are coated in zinc-rich paint)

3.4 Case 3: Monitoring behind over-cladding panels in Edinburgh

This study concerns the environmental monitoring of a prototype steel over-cladding panel constructed in August 1994 on the 8th floor of the James Clerk Maxwell building on the Edinburgh University campus, where the wind and rainfall regime is severe (see Figure 3.4). Over 200 galvanized steel coupons were positioned behind the over-cladding panels, as shown in Figure 3.5. The location of the coupons was chosen to be easily accessible. The coupons are removed every 6 to 12 months in order to determine the loss in weight of the samples and to observe signs of possible corrosion.

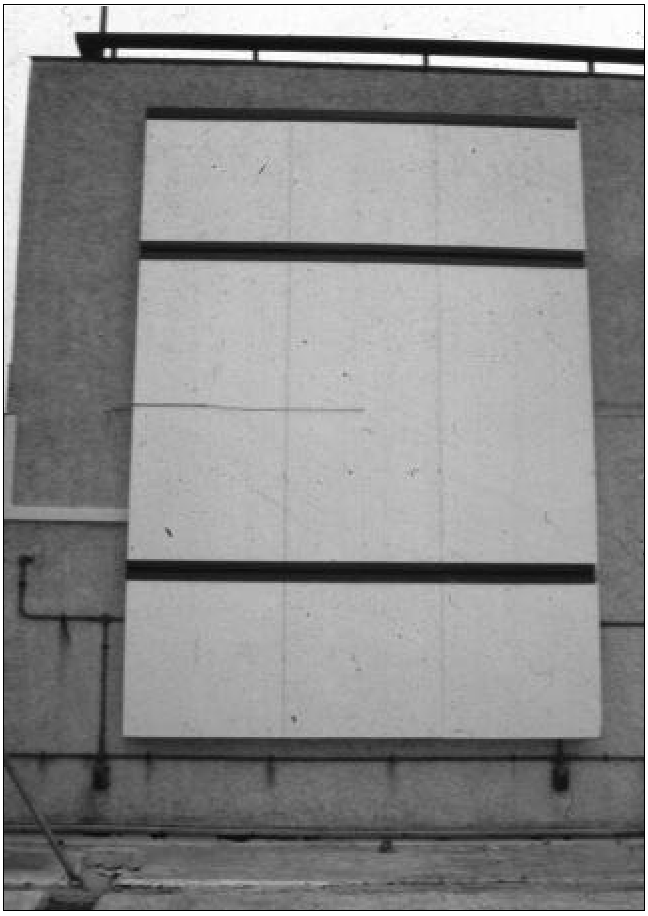

Figure 3.4 Over-cladding panel at Edinburgh University

Figure 3.5 Galvanized steel coupons installed behind the over-cladding panel

In this over-cladding application, the environmental conditions are potentially more severe, as although the cavity space is ventilated, the galvanized steel is subject to periodic wetness due to condensation and possibly to direct rain ingress. The bent shaped coupons were also designed to trap any moisture and were more susceptible to corrosion than the subframe or cladding members. The results of the samples removed to date are given in Table 3.3.

Table 3.3 Results of measurements on galvanized steel coupons installed behind the over-cladding panel at Edinburgh University

Exposure time (months)	Chromated zinc		Non-chromated zinc	
	Total loss (g/m^2)	**Rate of loss (g/m^2/year)**	**Total loss (g/m^2)**	**Rate of loss (g/m^2/year)**
6	0.98	1.96	1.78	3.56
15	0.97	0.78	2.1	1.68
24	0.76	0.38	3.3	1.65
57	1.83	0.38	4.05	0.85

G275 coating thickness. Data averaged over three specimens for each exposure time.

The total weight loss is measured from samples that are removed and weighed at the stated exposure time. The rate of zinc loss is the equivalent annual rate of loss averaged over the exposure time.

For chromated zinc samples, the average rate of zinc loss after 57 months was 0.38 g/m^2/year, although the rate of loss in the early months was much higher. For non-chromated zinc samples, the average rate of zinc loss was 0.85 g/m^2/year after 57 months and, in this case, the rate of zinc loss tends to be linear with time. As noted earlier, chromated zinc is the standard finishing later used for production of cold formed steel sections.

Despite the more severe conditions present in the cavity behind the over-cladding panels, the rate of zinc loss is not significantly higher than in the loft measurements of Case Study 1. The design life prediction is presented in Section 3.8.

3.5 Case 4: Monitoring the Oxford Brookes Demonstration Building

In 1996, a student residence was constructed at Oxford Brookes University as part of a European demonstration project. It used Corus's *Surebuild* light steel framing system. The building comprised a four-bedroom house and an adjacent six-room apartment building (see Figure 3.6). The house and apartments are occupied by postgraduate students.

The innovative feature of the building was the use of two alternative habitable roof systems, and a composite suspended ground floor system using a perimeter G-shaped galvanized steel edge beam with PMF CF70 decking and an in situ concrete slab spanning between these edge beams. The light steel framing and roof are also highly insulated to a *U* value of 0.2 W/m^2EC. The open habitable roof system is illustrated in Figure 3.7.

Figure 3.6 Oxford Brookes Demonstration Building

Figure 3.7 Open-roof system (kept open for demonstration purposes)

The building is being monitored over its life to assess its energy performance and the local temperature and humidity conditions that may exist in the building fabric. Importantly, crawl access is provided beneath the suspended ground floor to permit assessment of the performance of the galvanized steel substructure and composite floor. The first three years' data indicate that no wetness has occurred in the light steel frame, even adjacent to bathrooms, kitchens and in the roof space.

A series of zinc coupons has been suspended in the wall cavity and in the ventilated void below the suspended ground floor. These coupons have been removed at yearly intervals to assess the weight loss. The results after 30 months indicate that the rate of zinc loss averaged over the period is small (see Table 3.4). Data will be collected over the life of the building to form a reliable database to supplement previous studies.

Table 3.4 Measured weight loss of the galvanized steel coupons installed in the Demonstration Building at Oxford Brookes University

Location of coupons	Zinc loss after 30 months (g/m^2)	Rate of zinc loss (g/m^2/year)
Cold loft space adjacent to heated room	0.53	0.21
Suspended in cavity wall		
! high level	0.30	0.12
! low level	0.48	0.19
Below suspended ground floor	1.25	0.50

All data for chromated zinc specimens.

The research project has not been running for sufficient time to conclude whether the rate of zinc loss decreases with time but, at present, the equivalent annual loss, based on a linear rate, shows that the results are consistent with the data collected in Case Study 1 for a warm internal environment. The rate of zinc loss below the ground floor is much less than in Case Study 2.

3.6 Case 5: Japanese housing study

The Nippon Steel Corporation[15] has studied the durability of steel framed housing, including the connections between the components and other materials. Atmospheric pollution and humidity levels are high in certain parts of Japan. It might be expected that the rates of corrosion would exceed those in non-coastal areas of Europe.

Inside the test buildings, rates of zinc loss on the galvanized steel specimens were 0.3-0.5 g/m^2/year. This represents a rate of about one-twentieth of the rate of zinc loss of externally exposed specimens, where measurements of 5-15 g/m^2/year were recorded for the same building locations. The Japanese study concluded that galvanized steel has excellent durability in an internal environment, despite the often higher humidity and SO_2 levels that are present in the external environment.

Accelerated weathering tests were carried out on steel-steel and steel-timber connections. These tests showed no deterioration in the corrosion resistance of the fixings relative to that of the connecting strip steel.

3.7 Case 6: Monitoring studies of zinc loss and external environments in Europe

The United Nations Economic Commission for Europe commissioned a study for the International Co-operative Programme on Effects on Materials, including Historic and Cultural Monuments. In this study, the loss of zinc coating on specimens that were fully exposed to weather was measured together with the amount of atmospheric pollution at each exposure site.

The report of the study showed that in most of the European sites tested (see Table 3.5), zinc coatings suffered a corrosion rate in terms of thickness of between 1.0 and 1.5 μm per year. Some more polluted sites had a corrosion rate of 2.0 μm per year. At the higher rate, i.e. very severe exposure conditions, a standard G600 coating would be required in order to achieve a long design life in external environments.

*Table 3.5 Average performance of zinc coatings (Europe 1989-1993) on materials exposed to **external** environments* [9]

Country	Loss in zinc coating thickness	
	(g/m^2/year)	(μm/year)
Germany	8.6	1.2
England	8.3	1.2
Finland	7	1.0
The Netherlands	9.9	1.3
Norway	10.6	1.4
Russia	7.5	1.1
Spain	6	0.8
Czechoslovakia/Slovakia	8.7	1.2
Sweden	5.2	0.7
Average across Europe	7.9	1.1

Samples of steel and zinc were also exposed for two periods of 12 months at 32 test sites throughout Europe. The tests showed a linear relationship between the life of the zinc coating and the level of airborne SO_2 measured at each site [9].

3.8 Conclusions from case studies – design life of galvanized light steel frame sections

3.8.1 *Warm frame* applications

The monitoring studies have shown that the environmental conditions present in *warm frame* construction are such that moisture levels are very low and that the galvanized steel components are not subject to a risk of significant corrosion within the expected life of well maintained modern buildings.

The rates of zinc loss on chromated galvanized steel coupons are very low and, taking into account statistical accuracy, it has been observed that the rate of zinc loss reduces with time in dry environments. This is because of the zinc oxide layer that forms on the surface and protects the zinc beneath. However, it was observed that a linear rate of zinc loss with time is more appropriate for non-chromated zinc and for conditions with a potentially greater time of wetness. Chromated zinc is the coating normally used for the production of cold formed steel sections.

The following approach may be used to evaluate the design life of components that are concealed and cannot be inspected or repaired easily (Category A in Section 2.5):

- Assume a linear rate of zinc loss with time (which is a more conservative extrapolation of the data given by Equation 2).
- Assume that a loss of 50% of the total zinc coating may lead to some rusting of the surface (see *design life* definition in Section 2.5).
- Because the measurements are taken only from the average of three specimens, assume that the 95% probability level is double the average rate of loss. (This is justified by reference to Figure 3.1.)

In principle, the use of the 95% probability level means that the design life corresponds to the characteristic value, i.e. only 5% of the structure may suffer a more severe rate of zinc loss.

Therefore, the design life (in years) may be estimated from:

$$Design\ life = 0.25 \times \frac{Weight\ of\ zinc\ coating}{Average\ rate\ of\ zinc\ loss/year} \qquad (3)$$

The weight of zinc coating is expressed as the total weight (i.e. 275 g/m^2 for G275 specification); the rate of zinc loss is the weight loss summed over both faces. From the data in Case Studies 1, 2 and 4, the average rate of zinc loss of the frame components does not exceed 0.3 g/m^2/year. For G275 galvanizing, it follows that the design life is at least 230 years.

In comparison, Equation 2 would lead to a design life (calculated for 50% loss of zinc) given by:

$$137 = 1.0\ (\text{time})^{0.64}$$

or time = 2150 years.

This is almost 10 times longer than the linear estimate in Equation 3, because in Equation 2 the long-term rate of zinc loss is assumed to reduce in *warm frame* applications.

3.8.2 Roof space of houses

The roof space of houses may represent a more severe environment than a warm frame application, however from the data in Case Studies 1 and 2, the rate of zinc loss was not significantly higher. In the Oxford Brookes building, the roof space was insulated and the rate of zinc loss was very low. The data in Case Study 1 also include uninsulated lofts and the average rate of zinc loss was approximately 0.3 g/m^2/year.

Equation 3 predicts a design life of over 200 years but, given the potentially more variable conditions in lofts, it is considered that the design life of galvanized steel in these applications should be taken as:

- 100 years for insulated lofts
- 60 years for uninsulated lofts.

These predictions assume that the integrity of the roof is not impaired and that leaks are prevented.

3.8.3 Suspended ground floors

Suspended ground floors can incorporate light steel sections or decking. They are not exposed directly to moisture but may be subject to periodic condensation from humid air flow; however the risk of condensation is much reduced if the floor is insulated from below.

Case Studies 1, 2 and 4 provided data on the performance of uninsulated composite ground floors using light gauge decking. In Case Study 1, the rate of zinc loss was 1.22 g/m^2/year after five years, and in Case Study 4, the rate was 0.5 g/m^2/year. Equation 3 predicts a design life of 50-100 years in these conditions. However, the exposure severity can be reduced by using an external insulation layer beneath the floor, leading potentially to a design life of over 100 years. This type of floor is being further developed.

Any extrapolation from these data assumes that leaks from outside or inside the building envelope are prevented, that steel is not in direct contact with soil and is properly protected from other potential sources of moisture. Further data are being collected on all types of suspended ground floors.

3.8.4 Over-cladding applications

The light steel subframes to over-cladding systems are subject to variable conditions, depending on the exposure and type of cladding that is used. The Edinburgh University tests showed a rate of zinc loss of 0.38 g/m^2/year, which is relatively low for these exposure conditions. For these data, Equation 3 would lead to a design life of 180 years.

It is difficult to estimate the exposure conditions for all types of over-cladding system. With good detailing to avoid ingress of wind-driven rain, and to allow for some air movement in the cavity, a design life of at least 60 years may be expected for the subframe members, i.e. the rate of zinc loss would be less than 1.1 g/m^2/year. The more exposed members at the joints in the cladding should be additionally protected where they are subject to prolonged moisture.

3.8.5 Purlins and other roof members

Members or components that are fully exposed and can be inspected and repaired may be assessed differently. In this case, an 80% loss of zinc is taken to represent the design life (see Category B in Section 2.5). Therefore Equation 3 is modified to give:

$$\textit{Design life} \quad = \quad 0.4 \times \frac{\textit{Weight of zinc coating}}{\textit{Average rate of zinc loss/year}} \qquad (4)$$

For a building that is not heated continuously and is subject to some condensation, the rate of zinc loss is likely to be in the range of 1.0 to 1.5 g/m^2/year. This leads to a design life of over 60 years.

For a building that houses industrial processes, the rate of zinc loss may be higher. Similarly, for swimming pools and other high humidity applications, a greater thickness of zinc coating (typically G600), or a combination with a painted coating, is required.

Other design guidance on the use of galvanized steel in exposed or external environments is given in BS EN 14713[7].

4 DESIGN RECOMMENDATIONS FOR LONG DESIGN LIFE

The following recommendations are given to ensure a long design life in the use of light steel framing in housing. General detailing requirements are presented in the SCI publication *Building design using cold formed steel sections: Construction detailing and practice*[3], to which the reader should refer.

4.1 General detailing

- Provide a *warm frame* construction by placing the majority of the insulation on the external face of the frame or roof.
- It is generally not necessary to provide an additional vapour barrier on the warm side of the stud wall, as the inner layer of the plasterboard is generally suitable for this purpose.
- Provide drain holes in the bottom track to prevent any collection of water.
- Particular attention must be paid to:
  - detailing at window and door openings
  - detailing at floor and ceiling levels
  - avoiding penetrations or gaps in the insulation.
- The Building Regulations require forced ventilation to control humidity in kitchens and bathrooms, which reduces the risk of condensation in these areas.

4.2 Measures to control water penetration

- The external brickwork should be of good quality, to minimise water penetration into the cavity.
- Provide a nominal 50 mm cavity, to minimise potential bridging of the cavity by mortar droppings and to allow for ventilation. Taking into account construction tolerances, this cavity may reduce to a minimum of 40 mm in practice.
- Provide a water resistant barrier on the exterior of the wall studs. Closed cell insulation boards provide this function. It is not necessary to seal the joints in the insulation in most exposure conditions.
- Ensure that the roofing material prevents water leakage and that the roof is properly maintained.

4.3 Control of condensation

In light steel frame construction, a *warm frame* is achieved by positioning the insulation on the external face of the studs. Additional insulation may be located between the studs, but care must be taken to ensure that the calculated position of the dew point lies outside the zone of the studs. It is possible to calculate when the amount of additional insulation will cause *ghosting* of the plasterboard and the additional insulation should be kept below this level.

Calculations are carried out in accordance with Appendix D of BS 5250. A simple rule is that at least two-thirds of the insulation should be placed externally to the frame (i.e. to preserve the *warm frame*).

In cases of potentially high humidity, a vapour control layer may be used between the plasterboard and the light steel framing. Use of a foil-backed plasterboard or a separate polythene layer provides the same action.

4.4 Thermal insulation

A high level of thermal insulation can be provided by placing additional layers of insulation on the external face of the light steel frame. The minimum level of thermal insulation required by the Building Regulations can be achieved by a single 35 mm layer of closed cell insulation (to give a *U* value of less than 0.35 W/m^{2}EC). The Oxford Brookes Demonstration Building used two layers of closed cell insulation, and the monitoring study showed that the heat loss was consistent with a *U* value of 0.2 W/m^{2}EC. Also, 200 mm thick insulation layers were placed on the light steel roof components to achieve a similar *U* value.

A significant source of heat loss can be by air leakage through the building fabric. This can be kept to a minimum in light steel framing, because the closed cell insulation is largely impermeable, unlike blockwork construction. Nevertheless, as insulation levels increase, more care has to be taken to avoid heat loss due to air leakage. A continuous vapour control layer reduces air leakage.

4.5 Flooring

Joists in internal floors, or over enclosed basements, or not directly connected to exterior brickwork, are protected from aggressive environments. For joists that attach directly to concrete or an exterior wall, provide a damp proof course below the joists, and some other suitable protection where the joists are in contact with the wall (see below).

Floor joists or decking in suspended ground floors are more likely to be exposed to humidity for longer times. However, the data on zinc loss suggest that only the local areas directly exposed to continuous moisture, such as at the supports, require a greater level of protection. At the supports, an additional bituminous coating and a damp proof course should be used to provide suitable protection.

4.6 Good construction practice

The various conditions where galvanized steel sections are used in new construction and in renovation and special measures to ensure good performance in these applications are summarised in Table 4.1.

Table 4.1 Good construction practice to ensure durability in new and existing construction

Applications	Environmental conditions	Special measures
External walls	Warm: properly insulated and ventilated Cold: uninsulated, some risk of condensation	No special measures required Provide proper ventilation and reduce exposure. Over-cladding to an existing wall improves the insulation and life of the existing wall
Suspended ground floors	Cold: moisture from the ground and from the atmosphere	Provide good ventilation and avoid contact with ground. Use damp proof course at supports. See notes 1 and 2 for further protection
Roofs	Warm: properly insulated and ventilated Cold: uninsulated, some risk of condensation	No special precautions needed Provide proper ventilation. Over-roofing improves the life of an existing flat roof
Steel lintels	Wet: potential water ingress from cracks in brickwork Dry: no water ingress, properly drained	Use thicker grade of zinc coating. See notes 1 and 2 for further protection. Also see BS 5977-2:1983 No special measures required
Over-cladding	Drained and back-ventilated Pressure equalisation	Generally, no special precautions for weathertightness
Over-roofing	Cold environment, some risk of condensation	Generally, good ventilation is provided. Detail carefully at eaves level to prevent water ingress
In-fill walls for multi-storey buildings	Warm: properly insulated and ventilated	No special precautions needed
Contact with other materials	Contact with other metals Contact with plaster etc	See notes 3 and 4 below

General notes:

1. Where further protection is required, the surface may be painted or powder-coated. If aesthetic effects are unimportant, a well proven form of protection is to use a brush coat of bituminous paint.
2. Advice on painting galvanized steel is given in Appendix A.
3. Bimetallic corrosion of dissimilar metals should be avoided by using inert separators, especially between the fixings and cladding.
4. Zinc can be affected by contact with various building materials in damp conditions, for instance fresh concrete (highly alkaline), mortars, certain natural woods (oak and WRC are acidic), timber treatments (CCA is well-known but also phosphate fire retardants), and some insulation materials (which may contain inorganic salts, organic acids, or may just act as a source of moisture).

If the galvanized steel projects outside the envelope, such as in canopies, balconies or external supports, an additional coating or thicker galvanizing layer is required for maximum durability (see Appendices).

4.7 Measures to control damage on site

Reasonable precautions to protect steel during both transport and storage can prevent the risk of white rust. Storage should be indoors or under cover and preferably in a clean, dry area. Guidance on the interpretation and assessment of white rust deposits and other forms of discolouration, based on the information in *White rust in galvanised steel* [16], is given in Table 4.2.

Table 4.2 Surface discolouration of galvanized steel, and remedies[16]

Type of rust	Causes and conditions	Remedial action
Light *white rust*	Visible effect: thin white powdery deposits Caused by moisture trapped between sheets or components during transport or storage, or by condensation	None required. The protective properties of zinc are not impaired by the presence of superficial white rust. Existing white rust deposits will slowly convert to a protective layer of zinc carbonate if not removed by running water or brushing
Heavy *white rust*	Visible effect: thick, crusty deposit Caused by prolonged storage in damp conditions or inadequate protection during transport, allowing considerable water ingress between stacked sheets or components. In buildings, this can also occur where normal cycles of wetting and drying occur before completion of the building envelope	Remove small area of white rust by brushing (not a wire brush). Check residual zinc coating thickness with magnetic gauge. If within specification, or if the sheet or component is to be used in reasonably dry conditions, no action is required. However, if the component is to be exposed to conditions where moisture can be retained, the deposits must be removed. If below specification, clean the area and treat with an inorganic zinc-rich paint to a minimum dry film thickness of 25 μm or a bituminous paint
Red rust	Visible effect: thick red deposits Caused by corrosion of steel substrate where zinc coating has broken down completely. Should not be confused with superficial rust staining caused, for example, by small amounts of drilling swarf on the zinc surface or by wash from adjacent mild steel fixings	In general, sheets or components showing serious rusting should not be used. Expert advice should be sought on suitable coatings where rust is evident (see Appendix A)
Black staining	Caused usually by a very early stage of superficial zinc corrosion preceding white rust formation. Exceptionally, the cause may be exposure of iron/zinc alloy layer due to corrosion of the zinc top surface	Check zinc coating thickness using magnetic thickness gauge. If within specification, no action required. If below specification, treat as for heavy white rust

General notes to avoid damage or white rust during construction:

1. Always stack the packs on metal or wooden skids to keep them from direct contact with the ground.
2. Where possible, do not leave uncovered sections or sheet stacks lying in the open. Store them under cover and away from open doorways.

If it is necessary to store material out of doors, the following simple precautions are essential:

3. If sheets or sections cannot be kept under cover, erect a simple scaffolding around them and cover it with a waterproof sheet, tarpaulin or polythene. Leave space between the cover and the stacks or coils to allow air to circulate.
4. Store off the ground and on a slope so that any rain penetrating the cover will drain away.
5. Inspect the storage site regularly to ensure that, despite these precautions, the steel has not become wet.
6. Alternatively, use a steel stillage to stack the elements vertically rather than horizontally.

Careful storage and protection of materials on site also reduces the risk of damage and avoids any corrosion of exposed elements. A purpose-made steel racking system can be used to store the wall frames prior to their installation. Alternatively, the wall frames may be lifted directly from the lorry into position, which reduces the risk of damage.

Similarly, plasterboard, insulation boards, and flooring materials should be properly protected on site, as they may be a source of latent moisture and may be damaged by wetting.

5 CONCLUSIONS

Galvanized steel components are used in a wide range of building applications. In housing and residential buildings, galvanized sections with a G275 coating are used to create the primary framework, which is contained within the building envelope, in so-called *warm-frame* construction.

The following conclusions on the durability of cold formed galvanized steel sections were established by three programmes of research:

- monitoring the environments within buildings
- measurements of remaining zinc thickness on galvanized steel sections in various environments after up to 30 years of use
- measurement of zinc loss on coated coupons stored in various locations in the building envelope.

1. Control of moisture is effectively achieved in well ventilated areas within a *warm frame*. In such circumstances, the zinc coating will protect the steel adequately and will achieve a design life of at least 200 years, provided that the building envelope is properly maintained.

2. The measurements taken also indicate that the design life of light steel components and purlins in roofs is over 60 years, and that galvanized steel subframes used in over-cladding applications can achieve a design life of 60 years, when properly detailed to avoid water ingress.

3. In suspended composite ground floors, the rate of zinc loss is consistent with a design life of 50 to 100 years, provided that the steel elements are not in contact with soil or moisture from the ground. These conclusions are based on limited data, and further monitoring of these semi-exposed applications is in progress. External insulation beneath the floor decking will improve the design life and is recommended for these applications.

4. When galvanized steel sections are used, the following precautions are necessary to ensure adequate durability:

- Maintain the building envelope so that the conditions inside the building do not deteriorate.
- Prevent prolonged contact with moisture due to condensation or possible water ingress.
- Ensure that the galvanized steel is not directly in contact with aggressive or moist materials, e.g. in external walls or at foundations.
- Ensure that water will not become entrapped in the building envelope: water must be able to escape or must be kept out.

5. Zinc and zinc alloy hot dip galvanized coatings are an economical method of providing the long-term corrosion protection of steel framing members. The galvanizing process produces a tough metallic coating that can withstand the physical demands created during distribution, site storage and erection of the light steel framing members.

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RELEVANT STANDARDS

British Standards

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BS 1494-1:1964	Specification for fixing accessories for building purposes: fixings for sheet roof and wall coverings
BS 1706:1990	Method for specifying electroplated coating of zinc and cadmium on iron and steel (amended 1996)
BS 2989:1992	Specification for continuously hot-dip zinc coated and iron-zinc alloy coated steel flat products: tolerances on dimensions and shape (withdrawn; superseded by BS EN 10143)
CP 3012:1972	Code of practice for cleaning and preparation of metal surfaces (withdrawn)
BS 3083:1988	Specification for hot-dip zinc coated and hot-dip aluminium/zinc coated corrugated steel sheets for general purposes (replaced BS EN ISO standards)
BS 3382-2:1961	Specification for electroplated coatings on threaded components: zinc on steel components
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BS 4479-1-9:1990	Design of metal articles that are to be coated
BS 4921:1988	Specification for sheradized coatings on iron or steel
BS 417	Specification for galvanized low carbon steel cisterns, cistern lids, tanks and cylinders
BS 5411-8:1991	Methods of test for metallic and related coatings. Measurements of coating thickness of metallic coatings: x-ray spectrometric methods
BS 5427-1:1996	Code of practice for the use of profiled sheet for roof and wall cladding on buildings. Design
BS 5466:1995	Methods for corrosion testing of metallic coatings (now replaced by a series of BS EN ISO standards)
BS 5750:1987	Quality systems (withdrawn)
BS 5950-5:1998	Structural use of steelwork in building: code of practice for design of cold formed sections
BS 6100:1992	Glossary of building and civil engineering terms
BS 6150:1991	Code of practice for painting of buildings
BS 6338:1982	Specification for chromate conversion coatings on electroplated zinc and cadmium coatings
BS 6497:1984	Specification for powder organic coatings ... (on galvanized steel)
BS 6781:1986	Specification for continuously organic coated steel flat products (withdrawn)
BS 6830:1987	Specification for continuously hot-dip aluminium/zinc alloy coated cold rolled carbon steel flat products (withdrawn; superseded by BS EN 10215)
BS 7079:1990	Preparation of steel substrates before application of paints and related products
BS 7361:1991	Cathodic protection
BS 7543:1992	Guide to durability of buildings and building elements, products and components

BS EN 10215:1995	Continuously hot-dip zinc-aluminium (AZ) coated steel strip and sheet. Technical delivery conditions
BS EN 10143:1993	Continuously hot-dip metal coated steel sheet and strip. Tolerances on dimensions and shape
BS EN 22063:1994	Metallic and other inorganic coatings. Thermal spraying. Zinc, aluminium and their alloys
PD 6484:1979	Commentary on corrosion at bimetallic contact and its alleviation
EN 100880-1-3:1995	EC codes on stainless steel

ASTM Standards

A 90	Weight of zinc coating on iron and steel articles
A 123	Hot galvanized coating on fabricated products
A 153	Hot dip galvanized centrifugal components
A 325	High strength carbon steel bolts
A 490	High strength alloy steel bolts
A 525	Hot dip galvanized steel
A 633	Electroplated zinc articles

DIN Standards

DIN 267	Hot dip galvanized fasteners
DIN 509760	Protection by hot dip galvanizing: guiding principles
DIN 50976	Requirements and testing hot dip galvanized coatings on finished products
DIN 50978	Testing of adhesion of hot dip galvanized coatings
DIN 50933	Measurement of coating thickness using dial indicator
DIN 50981	Measurement of coating thickness: magnetic method
DIN 51213	Testing of zinc coating on wire
DIN 59231	Galvanized corrugated sheet
DIN 50961	Electroplating zinc
DIN EN22063	Zinc spraying

Swedish Standards

SS 3192	Hot dip galvanized threaded components
SS 055900	Blast cleaning steel
SS 3583	Principles and requirements for hot dip galvanizing

ISO Standards

ISO 1459	Protection by hot dip galvanizing: guiding principles
ISO 1460	Determination of hot dip galvanizing coating mass: gravimetric methods
ISO 1461	Requirements of hot dip galvanized coatings on fabricated components
ISO 1463	Measurement of coating thickness: microscopic method
ISO 2063	Metal spraying by zinc and aluminium
ISO 2064	Definition and convention concerning coating thickness methods
ISO 2081	Electroplated zinc coatings
ISO 2178	Measurement of coating thickness: magnetic method
ISO 3575	Continuous hot dip galvanized sheet
ISO 14713	A guide to the corrosion performance of hot dip galvanized steel (issued by BSI as BS EN ISO 14713)

APPENDIX A Guidance notes for specifiers painting galvanized steelwork

The following guidance notes concern the painting of galvanized steel components for visual or external applications.

A.1 Introduction

Galvanized (zinc) coatings are an excellent form of protection for steel but specifiers often use paint to improve the appearance. Furthermore, paint coatings should protect the galvanized steel for extended periods with little or no maintenance. At the works, proper procedures are normally in place to ensure good quality, but site painting practices may be of a lower standard. The preparation or initial priming stages are particularly important, and problems can almost always be traced back to an inadequacy in one of these steps.

Galvanized steel may have received a chemical wash designed to inhibit the development of white zinc salts in damp conditions. This is not the same as a conversion coating, which is the product of a carefully formulated process in which the metal surface is chemically modified by reaction with, for example, chromates or phosphates. Conversion coatings are an excellent first step at works but should not be specified for site painting unless the process can be controlled very tightly.

Works painting may have good quality control but damage may occur in transport and erection or installation. Specifiers should provide strict limits for the permissible degree of damage because site repairs often fail to match the quality of the original.

A.2 Preparation of surface

Hot-dip galvanized steel surfaces may have particles of dirt, grease and fluxing materials on them after delivering to site, and are likely to develop soluble zinc salts on the surface after storage or weathering. All these deposits are highly damaging to the adhesion of the subsequent paint films. Degreasing with swabs and white spirit is a widespread site practice but, as often as not, merely redistributes contaminants rather than removing them. A proper cleansing regime should be specified, using neutral detergent and abrasive pads, followed by copious washing (preferably powered).

Exposing zinc to the weather assists paint adhesion as it tends to etch the surface, however performance can be erratic and the weathered zinc must be cleaned rigorously.

Used correctly as indicators for showing whether the surface has been cleaned, mordant solutions of the T-wash type can be extremely useful, but it should not be assumed that their use guarantees long-term paint adhesion and eliminates the need for any other form of preparation. Furthermore, weld zones may show rusting in an otherwise well-protected structure. Site-welded areas must be made good prior to further painting, preferably on the same day and using an approved method of repair, such as application of a high quality two-pack zinc-rich paint after the heat affected zone has been dressed. If welding is an issue, it is useful to request that the contractor provides a finished example of the selected method of repair for approval prior to commencement of work.

A.3 Priming

Even when properly cleaned, raw zinc surfaces are not fully compatible with many priming paints. Although two-pack acid-etch primers give consistently reliable results when properly applied, they do have certain operational problems and are not recommended if operatives are unfamiliar with their use. It is bad practice to leave the primer exposed to the weather for extended periods and a compatible intermediate coat should be applied at an early stage.

Acrylic primers may be a better choice for site work; they generally give good performance and are a lot easier to use than the above materials.

Many manufacturers have their own in-house primer formulated specifically for zinc surfaces, but quality can vary, and specifiers considering their use should demand clear proof of performance.

A.4 Subsequent painting

Whatever the finishing system, it is imperative that it is compatible with the selected primer. The paint industry offers enormous choice to the specifiers and discussion with the coating supplier is always valuable. There may be particular reasons for specifying specialist products, but for many purposes the simpler the system the better. An applied sample of the proposed paint scheme on a galvanized panel, showing stripes of each coat, is a good reference point in cases of dispute.

APPENDIX B Guidance notes on sheet steel coatings

This Appendix provides an overview of the different types of sheet steel and their coatings. It is not definitive and is for general information only. Refer to the Corus publication *The Colorcoat Building*[17] for more guidance on coated sheeting.

B.1 Weathering steel (Corten steels)

Character: Corrosion resistant high tensile steels (Corten) are alloys formulated with small quantities of copper and other elements to form a tight, adherent rust layer that can be self-stifling with regard to further corrosion. They are sometimes called low-alloy or weathering steels. A typical formulation might include 0.5% copper, 04.% nickel, 0.7% chromium.

Usage: In the UK, Corten steel has mainly been used for specialist applications such as chimneys, containers and footbridges. In continental Europe, Corten steel has been used as sheet steel cladding. Corten is not generally used in coastal conditions, and produces a more uniform patina in areas of low humidity. In marine conditions, intensive rusting occurs and the rate of substrate consumption may be high.

B.2 Stainless steel

B.2.1 Stainless steels – natural finishes

Character: There are many grades of stainless steel, all characterised by significant chromium content. On exposure to air or water, a thin, stable, chromium-rich oxide film forms on the surface of these metals. This film provides a high degree of protection and, if damaged by abrasion, reforms rapidly.

Austenitic stainless steels are based on 17-18% chromium and 8-11% nickel additions and are the most widely used grades of stainless steel. Grades 1.4401 (316) or 1.4301 (304) are frequently used for structural and architectural applications.

Usage: Because of perceived price differentials, stainless steels have tended to be used more on prestigious projects or for structures in corrosive environments. However, despite the material cost being higher than some alternative materials, the whole life cost of a stainless steel component may not be significantly higher.

Stainless steels have a good record of performance in many different environments. Grade 1.4401 (316) has better pitting corrosion resistance than grade 1.4301 (304), due to the addition of the alloying element molybdenum. It is therefore the most appropriate grade to use for marine, industrial or polluted urban environments.

B.2.2 Stainless steels – coloured finishes

Character: The inert chromium-rich oxide layer on the surface of stainless steel can be modified by an electrochemical process to give a range of metallic colours. Their appearance will depend on the surface condition of the original material but colours include bronze, gold, red, purple and green.

Usage: Available in the UK for at least two decades, the use of coloured stainless steel has only increased in the last 3-4 years.

Electrolytically coloured stainless steels have corrosion resistance that is at least as good as the parent material. Sheets can be cut, bent and formed, and the colours are not susceptible to UV colour fade. The coloured layer is very thin, around 0.02-0.36 microns, so resistance to wear and abrasion is modest.

For general guidance on the use of stainless steel, refer to the SCI Publication *Architects' Guide to Stainless Steel*[18].

B.3 Metallic coatings

B.3.1 Zinc and zinc/iron alloy

Character: Unlike the hot dip batch process, continuous zinc coating of steel coil can be carefully controlled to produce a range of coating weights. In the UK, the working standard is 275 g/m^2 (i.e. a surface thickness *ca*. 20 microns).

Usage: Galvanized steel is widely used in light framing systems and in secondary members and decking. It is also used in applications such as purlins and side rails (see Section 2).

Zinc offers a reactive metal surface and forms a variety of salts when exposed to moisture. Oxides and carbonates are insoluble but chloride and sulphate ions tend to be water soluble. Also zinc is anodic to steel and corrodes preferentially, thereby protecting the steel by galvanic action.

In internal applications, the performance of galvanized steel is good and a long design life can be achieved. In external applications, zinc rarely weathers evenly, which can lead to patchy grey surfaces with high levels of dirt retention.

If overpainting is required, suitable surface preparation is critical (see Appendix A).

B.3.2 Zinc!aluminium alloys

Character: The standard alloy is the original Bethlehem Steel formulation 55% aluminium – 45% zinc. An alternative low aluminium product using 5% aluminium – 95% zinc is also used (e.g. *Galfan*).

Usage: Zinc!aluminium has similar durability to pure zinc coatings, depending on the environment. Like many zinc alloys, the high aluminium product can be offered in a more attractive initial spangle than pure zinc. In Australia, zinc-aluminium coatings are used in roofing and cladding.

B.3.3 Terne ! lead-based

Character: The term terne-coating is historically associated with lead-coated steels. The *lead* has of course been a lead–tin alloy for years. An 80% lead – 20% tin composition is standard.

Significant developments have occurred in recent decades. Coating finishes are much thinner (*ca*. 20 microns) and stainless steels appear to have replaced carbon steel as the basic substrate.

Usage: Terne is generally used as a roofing material to match the historic appearance of lead sheet. Although they should become uniformly dull in time, lead coatings weather unevenly and often remain patchy for some years. Bad detailing can aggravate this unevenness.

B.3.4 Terne ! lead-free

Character: A lead-free alternative to standard terne using a tin-based coating is available.

B.3.5 *Vitreous enamels*

Character: Glass-like finishes are applied as powders (frits) both dry and as slurries and are fused to form coherent coatings at high temperatures. A dark base coat is often applied as a substrate for the finish.

Usage: Exterior cladding, and pedestrian underpasses where ease of cleaning and resistance to graffiti are important functions. Vitreous enamel coatings have outstanding durability with excellent colour stability. They are usually associated with high gloss but lower gloss finishes are also available. They can be vulnerable to impact damage.

B.4 Organic coatings

B.4.1 General

Organic coatings are applied to the strip steel and are very versatile in application. There are many formulations in use, so it is not possible to discuss them all in detail. BS 6781:1986 (withdrawn) gives a list of the more common coatings available. The market is dominated by manufacturers offering one or more of the following coating types: heavy duty PVC, fluorocarbons, polyesters. The coatings are applied to the galvanized steel strip by first applying a pre-finishing treatment.

Different coatings may be provided as standard on the external and inner surfaces of the sheeting. The inner surface of the sheeting may well have a thinner finish as it is not exposed to the external conditions.

B.4.2 Polyvinyl chloride (PVC)

Character: Colorcoat HP200, manufactured by Corus, is the most well known organic coated sheet steel product in the UK. It has a thick textured PVC film (> 200 μm) in order to be resistant to wear and damage (including foot traffic in roofing applications). The strip steel is primed before coating.

Colorcoat HP200 is available in a wide range of colours. HP200C has a coating on the inner face that is suitable for more severe internal environments.

The new Colorcoat Celestia range is based on metallic finished organic coatings.

Usage: Roof and wall cladding; composite panels for walls. PVC coatings are used in a range of applications and are available in many colours (see Celestia range).

Guidance on Colorcoat products is presented in the Corus publication *The Colorcoat Building*[18]. Corus guarantees the performance of its products in the UK according to a *Period to Repaint Decision*, depending on the application and environment. Some colours are less resistant to ultra-violet light (i.e. strong sun) than others.

B.4.3 Fluorocarbon coatings

Character: Wet-applied fluorocarbons are usually referred to as PVF2 or PVDF coatings. Blending is necessary to obtain proper coating character and PVF2/acrylic blends are the norm. For good weathering performance, 70% PVF2 is the usual formulation standard for exterior quality.

Usage: PVF2 is widely used as a decorative finish because of its good colour retention, but is not well suited to roofing because of its vulnerability to damage by foot traffic.

B.4.4 Polyesters

Character: Polyesters are often used in the form of powder coating for discrete items for post-fabrication finishing. Pre-finished steels generally use wet-applied unmodified or silicone modified polyesters.

Usage: Polyesters are tough and durable (the unmodified types are known to be more vulnerable to chalking but are better for forming purposes). The finish comes in various degrees of gloss with good colour retention, although there can be a degree of dirt retention with the silicone modified versions. Remedial coatings for clad surfaces are often of this type.

B.4.5 Miscellaneous coatings

Apart from the materials discussed above, the list in BS 6781 refers to alkyds, acrylics, epoxies, polyurethanes, silicone modified acrylics, PVC organosols, PVC copolymers, and various forms of applied laminate film.

Alkyds are used on internal surfaces but should not be used for exterior exposure. Even stoved versions have limited durability and are subject to chalking.

Acrylics have not found much favour in the UK, although they are used in Japan and the USA. They were displaced in the aluminium market by powder coatings. They have good colour retention and durability but can get dirty. They have been used as textured coatings on, for instance, steel roofing tiles such as those from Tileform and Decra.

Epoxies are usually found as thin priming coats for PVF2 or as barrier coats. Finishes are tough and durable but chalk badly when exposed to the weather in the UK. They perform well internally.

Polyurethanes are good decorative products that have been used successfully. To take one well-known example, *Versacor* is based on an epoxy barrier coat topped with either polyurethane or PVF2.

APPENDIX C Contact Information

C.1 Associations

Steel Frame Homes Association
PO Box 20260
London
NW1 5ZP
Tel: 020 7222 4912 Fax: 020 7222 5412

Galvanizers Association
Wren's Court
56 Victoria Road
Sutton Coldfield
B72 1SY
Tel: 0121 355 8838 Fax: 0121 355 8727

Cold Rolled Section Association
Secretary: Robson, Rhodes Chartered Accountants
Centre City Tower
7 Hill Street
Birmingham
B5 4UU
Tel: 0121 697 6000 Fax: 0121 697 6113

C.2 Principal manufacturers of light steel framing for residential applications in the UK

A comprehensive list of cold formed section manufacturers can be obtained from the Cold Rolled Section Association.

Ayrshire Steel Framing
Irvine
KA12 8PH
Tel: 01294 274171 Fax: 01294 211231

The Forge Company (UK) Ltd
105-109 Strand
London
WC2R 0AA
Tel: 020 7836 7887 Fax: 020 7836 6020

British Steel Framing (incorporating *Surebuild*)
Corus Building Systems
Whitehead Works
Mendalgief Road
Newport
NP19 0XN
Tel: 01633 244000 Fax: 01633 211231

Metsec Framing Ltd (incorporating Metframe and Gypframe)
Broadwell Road
Oldbury
Warley
B69 4HE
Tel: 0121 552 1541 Fax: 0121 544 6779

Ward Building Components Limited
Sherburn
Malton
YO17 8PQ
Tel: 01944 710591 Fax: 01944 710555

C.3 Steel strip manufacturer

Corus Colors (formerly British Steel Strip Products)
Technical Advisory Service
Market Development
Commercial Office
PO Box 10
Newport
NP19 0XN
Tel: 01633 464646 Fax: 01633 464080

C.4 Other companies involved with cold formed steel framing systems for building

British Gypsum Limited
Head Office
East Leake
Loughborough
LE12 6JT
Tel: 0115 945 1000/6123 Fax: 0115 945 6356

Britspace Modular Building Systems Limited
Broad Lane
Gilberdyke
Brough
HU15 2TS
Tel: 01430 440673 Fax: 01430 441958

Knauf Limited
PO Box 133
Sittingbourne
ME10 3HW
Tel: 01795 424499 Fax: 01795 428651

Larfarge Plasterboard Limited
Easton in Gordano
Bristol
BS20 0NF
Tel: 01275 377789 (Tech) Fax: 01275 372018 (Tech)

Structural Sections Limited
PO Box 92
Downing Street
Smethwick
Warley
B66 2PA
Tel: 0121 555 5918 Fax: 0121 555 5659

Terrapin Limited
Bond Avenue
Bletchley
Milton Keynes
MK1 1JJ
Tel: 01908 270900 Fax: 01908 270052

Yorkon Limited
New Lane
Huntington
YO3 9PT
Tel: 01904 610990 Fax: 01904 610880