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Durability of Light Steel Framing in Residential Building

Second Edition

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FOREWORD

The Second Edition of this publication updates and extends the durability data and design life predictions for galvanized light steel framing presented in the First Edition. Recently recorded durability data is included for several buildings using light steel framing. This data has been recorded for more than 10 years and permits a confident prediction of design life.

The work of collecting and presenting the data was carried out by Andrew Way of The Steel Construction Institute, Trevor Heatley and Vernon John of Corus and Dr Sunday Popo-Ola of Imperial College. The author gratefully acknowledges the assistance given by Prof Mark Lawson, SCI Professor of Construction Systems at University of Surrey and Clive Challinor of Corus Strip Products UK (CSPUK).

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Guidance on the applications of light steel framing in housing and other residential buildings is given in SCI Publications P310 and P302.

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SUMMARY

This publication presents a summary and analysis of research findings on the durability of galvanized cold formed steel sections used in housing; the results are used to calculate the predicted design life. These sections are produced from pre-galvanized strip steel. It reviews reports and publications from research projects carried out by Corus, BRE, ECSC, SCI and the former DETR on zinc coated cold formed steel sections. New data have also been collected from measurements on houses and similar buildings that use galvanized steel components.

The performance of galvanized (zinc coated) steel components within protected environments (e.g. 'warm frame' applications) is very good. This research shows that the predicted design life of the standard Z275 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 summarizes the expected design life of galvanized steel sections in common applications in buildings. Additionally, 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 conditions	Predicted design life
Walls and floors in warm frame applications	No risk of water ingress or condensation	250 years
Non-load bearing stud partitions	Warm internal environment and no risk of water ingress	250 years
Infill external walls in multi-storey buildings	Warm frame and no risk of water ingress	250 years
Roof structures (insulated)	Low risk of condensation	200 years
Suspended ground floors (with over-site membrane)	Low risk of water ingress; some risk of condensation	100 years
Roof structures (uninsulated)	Some risk of condensation	100 years
Purlins and side rails supporting metal cladding	Low risk of condensation; some dust and pollution	60 years
Sub-frames to over-cladding panels	Low risk of water ingress; some risk of condensation	60 years
Suspended ground floors (without over-site membrane)	Low risk of water ingress; higher risk of condensation	50 years

Note: All values are for Z275 (Total weight of zinc coating on both surfaces = 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's frame.

1 INTRODUCTION

Galvanized steel has been used successfully for over 60 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, nearly 500,000 homes have been built with steel framing over the past decade, 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 has grown to approximately 13% (17,000 new homes per year).

In the UK, the current market for light steel framing is lower, but is increasing; light steel has been used in housing for over 20 years.

Many steel housing systems were marketed in the UK between 1920 and 1970[1], but 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 80 years old, has generally been good despite some poor construction details employed when building physics issues were less well understood.

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 protects the steel in two ways. Firstly, the zinc coating acts as a physical barrier between a potentially corrosive environment and the steel base. Secondly, protection is provided through galvanic or sacrificial protection at cut edges and scratches. Modern light steel framing uses ‘warm frame’ construction where all the light steel framing is in a warm, dry environment hence the risk of moisture within the building envelope is largely eliminated. Sections 2 to 4 illustrate the excellent durability performance of light steel when used in modern well-detailed construction.

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. Data has been collected through exposure trials and monitoring of buildings in the UK, Finland, Portugal, Japan, Australia and the USA, and this data supports the conclusions of this report. General guidance on the use of zinc coatings for corrosion protection can be obtained from the Galvanizers Association.

1.1 Advantages of light steel framing

Galvanized cold formed steel sections are 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, achieved by pre-fabrication of the wall panels and their easy assembly 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 sustainability and energy efficiency benefits of steel construction are explained in detail in SCI publications P370[2] and P367[3].

1.2 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. Small components and sections of varying shape are produced by press braking.

The use of prefabricated wall panels facilitates the creation of 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 allow all the structural and building physics performance requirements of the Building Regulations to be met.

The cold formed steel sections used in residential light steel framing are typically C or Z shape sections. The sections are joined using bolting, self-drilling self-tapping screws, riveting, 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).

Most light steel framing systems in residential construction use wall panel construction, as illustrated in Figure 1.1. Typically, standard 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. Steel decking has been used in composite floors in light steel frame construction, including suspended ground floors.

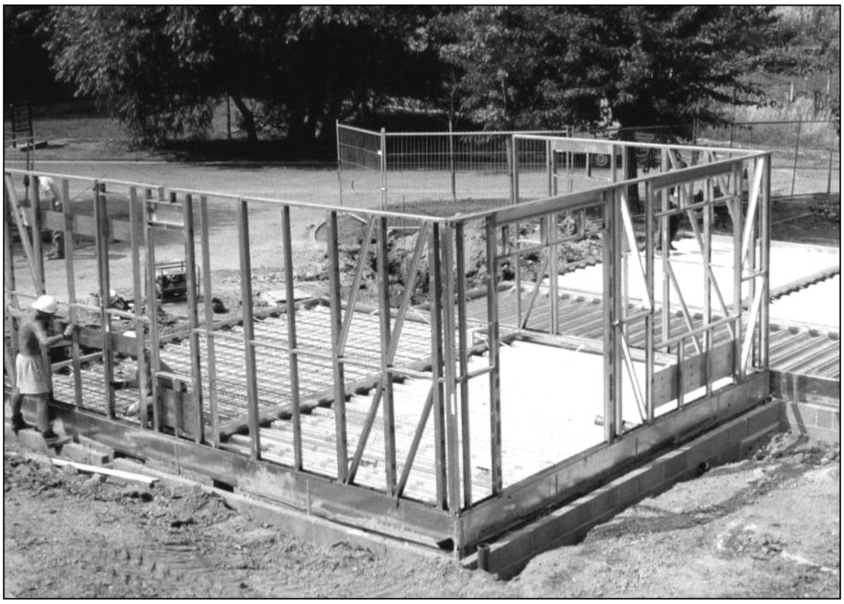

Figure 1.1 *Installation of ground floor walls in light steel framing for housing*

The sections are usually rolled from pre-galvanized sheet steel that is typically 0.9 to 3.2 mm thick with a Z275 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.

Guidance on the use and design of light steel framing in housing and other residential buildings is given in the SCI publications P301 *Building design using cold formed steel sections: Light steel framing in residential construction*[4], and P302: *Modular Construction using light steel framing: Design of residential buildings*[5].

1.3 'Warm frame' construction

In 'warm frame' construction, the cavity faces of an external wall frame are 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.

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.

Figure 1.2 *'Warm frame' construction showing external insulation*

1.4 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:

- Cold roof, in which the roof acts only as a weather tight barrier
- Warm roof, in which the roof is insulated, so that the space under the roof is relatively warm.

1.5 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 normally in the warm internal environment, but 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.

1.6 Ground floors

A small number of projects have successfully used suspended composite ground floors that utilise 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 by provision of an over-site membrane.

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.

1.7 Types of galvanized coating

The standard form of corrosion protection for cold formed steel sections is the continuous hot-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 specifications in BS EN 10346[6],and BS EN 10143[7].

The zinc adheres to the steel substrate and deforms without cracking or becoming detached around the bends during forming, even in complex section shapes. 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 usually produced with a standard Z275 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[8]. More guidance on this technology is available from the Galvanizers Association.

Zinc-aluminium coatings are also available, and are used in some countries such as Australia, particularly for roofing and cladding applications. The relative proportion of aluminium can vary from 5% to 55% by weight.

BS EN ISO 14713[9], provides information on zinc and aluminium coatings and their expected design lives in different environments.

Zinc-magnesium coatings have been developed and are starting to become commercially available. These are relatively new and are more commonly used in the automotive sector than the construction industry.

1.8 Performance of galvanized steel products

Galvanized steel has been used for over 60 years in a wide range of building components in the UK, even if its use in light steel framing 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
- Plates for connecting 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.

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 SCI publications P301[4] and P302[5].

Section 3 presents a review of case studies into the performance of galvanized steel in residential buildings. Section 5 identifies the conditions where control of condensation or other moisture contact is necessary in order to ensure long-term durability of the zinc coating.

1.9 Other durability benefits of steel

In addition to the durability of the galvanized coating, 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 water overflow (provided that this is an infrequent occurrence)
- galvanized steel does not suffer from fungal or biological deterioration
- any local damage can be identified and rectified
- steel is non-combustible and fire resistant
- steel is not susceptible to insect infestation
- steel is of reliable and high uniform quality
- steel is not affected adversely by normal temperature ranges

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 80 years of excellent performance since the 1920s.

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

- Encapsulation - where a coherent barrier is used to exclude corrosive agencies from the surface.
- 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 standard coating is Z275 (i.e. 275 g/m^2). This equates to a coating thickness of about 20 microns on each side, if it is evenly distributed over both sides. The Z275 grade was formerly used in BS 2989 and has now been incorporated within BS EN 10346[6]. The coatings are thinner than those formerly specified (in BS 729) 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 coated steel strip. Corus's product name *Galvatite* will be known to many specifiers.

Post-galvanizing treatments may be offered to protect the zinc coating during transportation and storage. These passivation systems, which traditionally have been chrome-based, suppress the development of white zinc corrosion products that can form in continuously wet conditions, such as when water is trapped between the sheets. New alternative passivation treatments to chromate-based systems have been developed and are starting to become commercially available. A thin film of mineral oil can be 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 in exterior environments

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

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 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 galvanized product has not fundamentally changed over the last 30 years, the expected product lifetime in external atmospheres has almost doubled in the UK as a consequence of improved air quality. This has enabled hot-dip galvanized coatings to protect steel for longer periods, and newly manufactured components have a much longer life expectancy than would have been predicted 30 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.

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/m^2/year or 0.03 mm/year[10]. 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.

Corrosion Maps published by the Galvanizers Association[11] show the corrosivity of the atmosphere across the UK and indicate the expected lifetime of a fully exposed 85 micron (G600) galvanized coating. (Note: This is not the Z275 coating typically used on light steel framing.)

The approximate performance of zinc coatings in different environments is shown in Table 2.2, which is taken from EN ISO 14713[9]. The lifetime of zinc coatings has improved, and research work suggests that these figures are conservative[12].

Table 2.2 *Performance of zinc coatings in different environments (from EN ISO 14713)*

Code		Environment	Corrosion risk	Average reduction in coating (microns/year)
C1	Interior:	Dry	Very low	≤ 0.1
C2	Interior: Exterior:	Occasional condensation Exposed rural inland	Low	0.1 - 0.7
C3	Interior: Exterior:	High humidity, some air pollution Urban inland or mild coastal	Medium	0.7 - 2.0
C4	Interior: Exterior:	Swimming pools, chemical plants etc. Industrial inland or urban coastal	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, consists of a mixture of zinc compounds, including zinc carbonate, zinc oxide and zinc hydroxide. Environmental factors dictate which of these compounds are formed.

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, with a commensurate increase in life expectancy for galvanized coatings.

2.2.2 White rust on galvanized steel sections

White rust is a corrosion product of zinc formed from hydrated zinc carbonate/ zinc hydroxide 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 5.2.

To inhibit the formation of white rust during material transport or storage, a passivation film, or oil film, can be applied to the galvanized steel during manufacture. For some of the case studies presented in Section 3, some of the test coupons had been passivated with a chromate-based solution. As expected, the passivation affords slightly lower rates of corrosion. The performance of the passivation can be variable and there are different types of passivation which will provide different levels of protection. Results from passivated and non-passivated coupons are included in Section 3 for comparison. However, the design life predictions are based on the durability results of the non-passivated galvanized steel coupons.

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 longitudinal 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. However, 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 longer the design life. The rate of zinc loss in an internal environment is 10 times slower than 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 modern houses have 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 caused by the high sulphate content of some brick/mortar types, coupled with moisture penetration into the outer brick leaf.

As a result of surveys carried out by the Building Research Establishment in the late 1970s, 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. BS 1243[13] was consequently revised in 1981 (BS 1243 is now superseded by BS EN 845-1[14]). The database from that research is given in BRE Digest 401[15] (also in IP 16/88 and IP 12/90). 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.

2.4.2 Galvanized steel lintels

Most lintels used in modern housing are made of galvanized steel, and their 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. Steel 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.

Steel lintels can be manufactured from pre-galvanized strip or post-galvanized after fabrication. Pre-galvanized lintels are often painted after fabrication for additional protection. Lintels galvanized after fabrication have every surface, cut edge, and weld treated to ensure that they are fully protected. This post-galvanizing process creates a build-up of zinc protection at the most vulnerable points (e.g. 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[8]. Furthermore, Annex C of BS EN 845-2[16] gives specific requirements for the protection of steel lintels.

The service life of steel 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 EN 845-1[14]. 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 50 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 typically dusty and humid factory environments has been good since these components came into service over 40 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 1.2, 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. The design life does **not** represent structural failure of the component, and there may be a considerable margin between the design life of the protective system and potential structural failure.

Two categories of component may be defined that influence the approach used to determine the design life:

- **Category A:** Components that are concealed or encapsulated and cannot be inspected regularly.
- **Category B:** Components that are exposed so that they can be inspected readily, such as by removal of inspection panels or trapdoors.

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
- **Category B:** when 80% of the weight of zinc has been lost.

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. 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 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 should give 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.

Table 2.3 *Hierarchy of importance in terms of durability*

Column (heavily loaded)	Most important
Concealed tension tie (e.g. in truss)	↓
Beam (supporting a floor)	
Exposed tension tie (e.g. canopy)	
Wall panel (load bearing)	
Bracing (at ground floor level)	
Lintel above large opening	
Joist hanger	
Floor joists	
Floor decking (internal)	
Roof purlins	
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	Least important

3 CASE STUDIES OF DURABILITY MEASUREMENTS

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 of older buildings

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 UK Government supported performance monitoring

The former Department of the Environment (now Department for Communities and Local Government) sponsored a three year corrosion and environmental monitoring exercise in fifteen houses in Manchester, London and South Wales[12]. 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.

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 is taken from a research report[12] from the former British Steel. 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 this data, the average rate of zinc loss was approximately 0.3 g/m^2/year. Chromated galvanized steel was found to have a slightly lower rate of zinc loss than non-chromated galvanized steel. The data is subject to some variability in exposure conditions and surface characteristics among the specimens.

Table 3.1 *Durability performance of specimens in a loft environment*

Materials	Average weight loss of specimens (g/m^2) Number of years exposure		
	1 year	2 years	3 years
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	7.00

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 Interpretation of zinc loss

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

$$\text{Weight loss per surface} = a\,(\text{time})^{b} \qquad (1)$$

where time is measured in years.

A difference in performance was observed between chromated and non-chromated zinc specimens.

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 twice the mean of the data (see Figure 3.1). The expression becomes:

$$\text{Weight loss per surface} = 1.0\,(\text{time})^{0.64} \qquad (2)$$

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

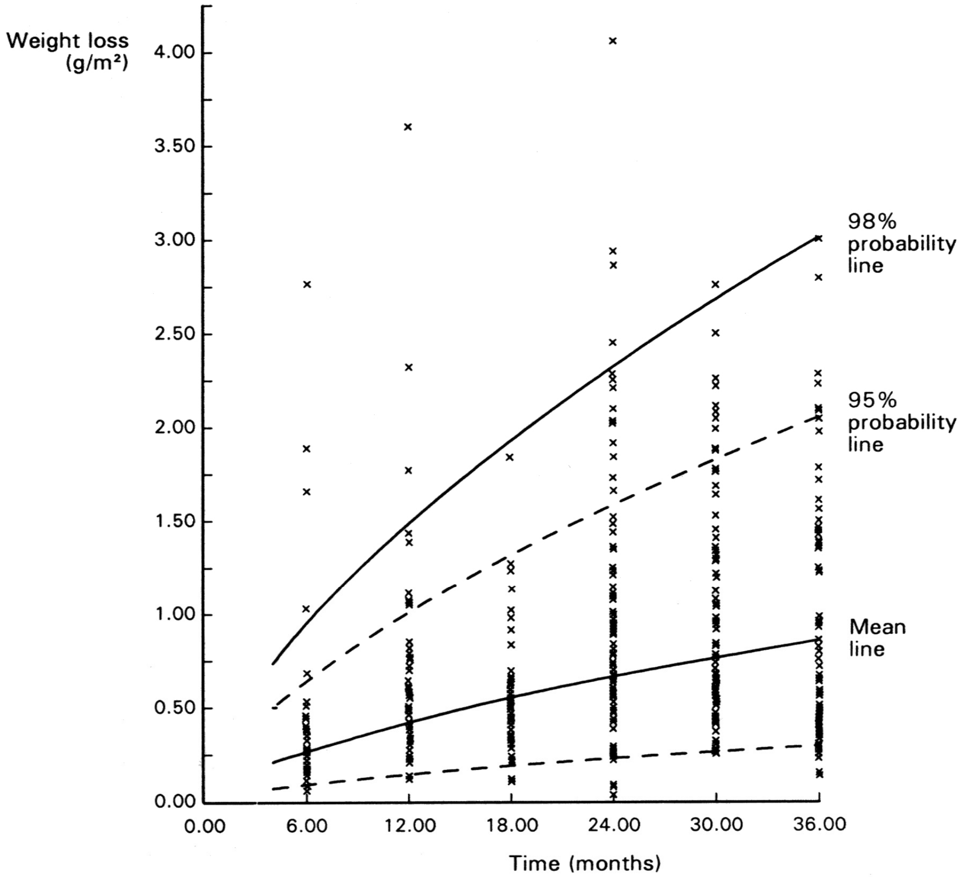

Figure 3.1 *Zinc weight loss with time for freely exposed hot-dip galvanized steel specimens*

3.3 Steel framed building at Ullenwood

The residential building illustrated in Figure 3.2 was monitored to gain data on in-service durability performance of galvanized steel. 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 (now Corus Panels and Profiles) in 1982. Areas investigated were the environmental conditions in the wall cavity, the loft and below the suspended ground floor[17]. 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 a five-year period.

Figure 3.2 *Light steel framed building for disabled persons at Ullenwood*

The hot-dipped galvanized coating on the steel coupons was post-bath chromated with a chromium layer 0.0035 g/m^2 for added protection.

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	Exposure time (months)	Total loss (g/m^2)	Rate of loss (g/m^2/year)
Wall space	6	0.09	0.18
(in cold cavity)	12	0.27	0.26
	18	0.30	0.20
	24	0.41	0.20
	60	1.20	0.24
Loft space	6	0.09	0.18
(cold frame)	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
Below ground floor	60	6.10	1.22

Notes:
Rate of zinc loss is averaged over the exposure time.
Measurements of zinc loss are for two surfaces

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 was 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.

Figure 3.3 *Wall panel removed, showing no trace of corrosion on the members after 14 years (the connections are coated in zinc-rich paint)*

The measurements taken of the specimens under the ground floor were affected by their close proximity to an air-brick in the external cladding and by the lack of an over-site membrane beneath the suspended floor. The rate of zinc loss after five years was 1.22 g/m^2/year. The presence of over-site membrane would have reduced the rate of corrosion by reducing the amount of moisture in the air below the slab. The advantages of an over-site membrane are shown in the case study in Section 3.4, where the zinc loss below a suspended ground floor was only 0.20 g/m^2/year.

3.4 Light steel demonstration building at Oxford Brookes University

In 1996, a student residence was constructed at Oxford Brookes University as part of a European demonstration project. It used the Corus *Surebuild* light steel framing system. The building comprised a four-bedroom house and an adjacent six-room apartment building (see Figure 3.4). 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 (now Corus Panels and Profiles) 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^2K. The open habitable roof system is illustrated in Figure 3.5.

Figure 3.4 *Oxford Brookes Demonstration Building*

Figure 3.5 *Open-roof system in the Oxford Brookes House*

The building was monitored to assess its energy performance and the local temperature and humidity conditions that may exist in the building fabric. Crawl access is provided beneath the suspended ground floor to permit assessment of the performance of the galvanized steel substructure and composite floor. The data indicated that no wetness has occurred in the light steel frame, even adjacent to bathrooms, kitchens and in the roof space.

A series of coated steel coupons were suspended in the wall cavity, loft and in the ventilated void below the suspended ground floor. These coupons were removed at intervals to assess the weight loss. A summary of the results is given in Table 3.3.

Table 3.3 *Measured weight loss of the galvanized steel coupons installed in the Demonstration Building at Oxford Brookes University*

Location of coupons	Exposure time (months)	HDG	
		Total loss (g/m²)	Rate of loss (g/m²/year)
Cold loft space adjacent to heated room	30	0.53	0.21
	60	0.57	0.11
	124	0.63	0.06
Suspended in cavity wall - high level	30	0.30	0.12
	60	0.47	0.09
	124	0.45	0.04
Suspended in cavity wall - low level	30	0.48	0.19
	60	1.25	0.25
	124	1.31	0.13
Below suspended ground floor	30	1.25	0.50
	60	2.13	0.43
	124	2.04	0.20

Notes:
Coupons used for 30 and 60 months exposure were chromated.
Coupons used for 124 month exposure were non-chromated.
Values are averaged over at least two specimens for each exposure time and location
HDG is a hot-dipped galvanized zinc coating of 275 g/m²
Measurements of zinc loss are for two surfaces

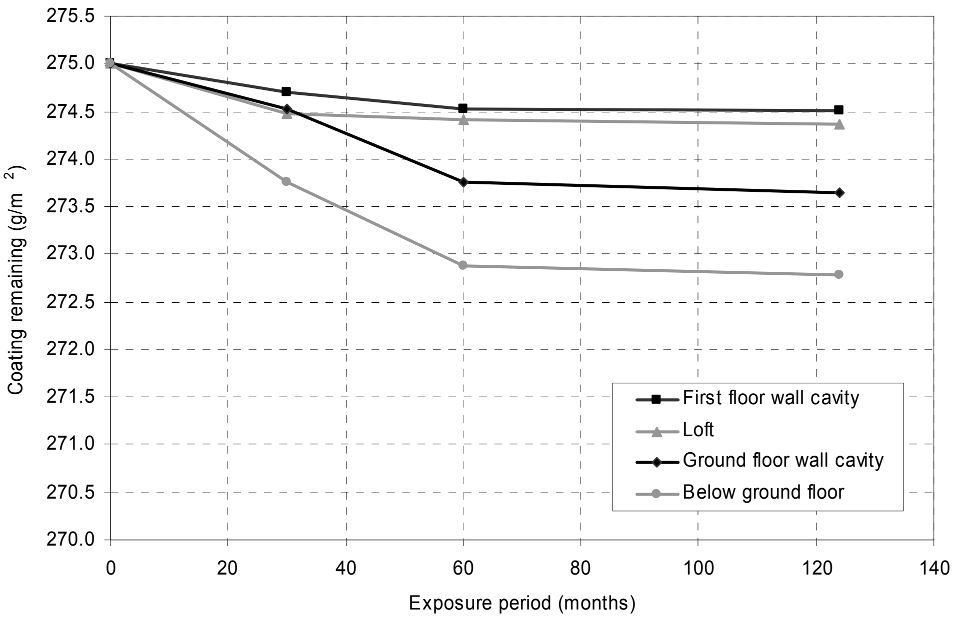

Figure 3.6 *Graph showing durability performance of hot-dip galvanized coating at Oxford Brookes demonstration building*

The results show that the average rate of loss of coating per year reduces as the period of exposure increases. The graph in Figure 3.6 shows the amount of zinc coating remaining for coupons placed in different locations around the building.

It can be seen that the amount of coating that is lost between 60 and 120 months (a 5 year period) was very small.

As expected, the coupons below the ground floor slab suffered the highest rate of loss of coating. However, the rate of corrosion was limited by the provision of an over-site membrane (see Figure 3.8), which reduces the amount of moisture in the air below the slab. The observed rate of corrosion is low and the condition of the galvanising is excellent after over 10 years of service as shown by Figure 3.7.

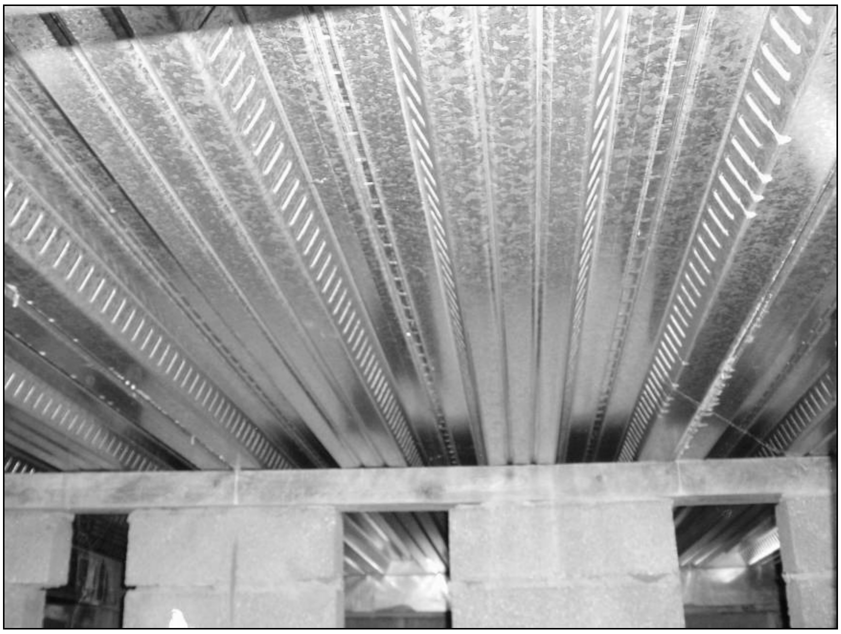

Figure 3.7 *Galvanized steel decking forming the underside of the suspended composite ground floor slab after 124 months*

Figure 3.8 *Over-site membrane applied beneath the suspended composite ground floor slab (during construction)*

3.5 Insulated over-cladding panels in Edinburgh

Durability monitoring was carried out on over-cladding systems used in building renovation. Galvanized steel coupons were installed behind two different types of over-cladding systems constructed at Edinburgh University. Section 3.5.1 describes a durability monitoring study conducted over 13 years which involved composite over-cladding panels. Section 3.5.2 describes a durability monitoring study conducted over 10 years which involved a steel cassette over-cladding panel system. Both over-cladding systems are shown in Figure 3.9. The large panels on the left are the composite panels and the smaller panels on the right are the steel cassette panels.

In over-cladding applications, the environmental conditions are potentially more severe than internal conditions because although the cavity space is ventilated, the galvanized steel is subject to periodic wetness due to condensation and possibly by direct rain ingress.

Figure 3.9 *Over-cladding panels monitored on the 8th floor of a building at Edinburgh University*

3.5.1 Composite over-cladding panels

The panels were constructed in August 1994 on an exposed west facing wall of the 8th floor of the James Clerk Maxwell building on the Edinburgh University campus, where the wind and rainfall regime is severe. Over 200 galvanized steel coupons were positioned behind the over-cladding panels, as shown in

Figure 3.10. The coupons were removed at regular intervals to determine the loss in weight of the samples and to observe signs of possible corrosion.

Chromated and non-chromated zinc coupons where installed behind the composite over-cladding panels in order to assess the effect of passivation provided by the chromated finish. L-shaped coupons were used to trap any moisture that may enter the air cavity (see Figure 3.10). The chromated and non-chromated zinc coupons after 13 years exposure are shown in Figure 3.11. The results of the measurements at various intervals are given in Table 3.4.

Figure 3.10 *Galvanized L-shaped steel coupons installed behind the composite over-cladding panels in Edinburgh*

Figure 3.11 *Chromated and non-chromated zinc coupons after 13 years exposure (non-chromated zinc coupon on right)*

Table 3.4 *Measured weight loss of the galvanized steel coupons installed behind composite over-cladding panels at Edinburgh University*

Location of coupons	Exposure time (months)	Chromated HDG		Non-chromated HDG	
		Total loss (g/m^2)	Rate of loss (g/m^2/year)	Total loss (g/m^2)	Rate of loss (g/m^2/year)
Behind composite over-cladding panel	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
	156	3.87	0.30	5.61	0.43

Notes:
HDG is a hot-dipped galvanized zinc coating of 275 g/m^2
Data averaged over three to six specimens for each exposure time
Measurements of zinc loss are for two surfaces

The total weight loss was measured from samples that were 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. Over time, the average rate of loss per year has significantly reduced for both types of coating.

3.5.2 Steel cassette over-cladding panels

In this over-cladding system, the flat steel cassette panels are fixed to vertical galvanized U-shaped rails.

A 2 m by 3 m test panel consisting of four individual cassettes, which has a warm air cavity, was constructed on the 8th floor of the west facing wall of the James Clerk Maxwell Building at Edinburgh University. Flat galvanized steel coupons were suspended in the air cavity behind the cassette panels (see Figure 3.12).

The coupons installed were hot-dipped galvanized steel coupons with a total zinc coating of 275 g/m^2 and were non-chromated. The coupons were installed in October 1996.

Corrosion was assessed by measuring the weight loss of the protective coating during the exposure period. Coupons were collected for analysis after exposure periods of 60 months and 128 months. The results are shown in Table 3.5.

Table 3.5 *Measured weight loss of the galvanized steel coupons installed behind steel cassette over-cladding panels at Edinburgh University*

Location of coupons	Exposure time (months)	HDG	
		Total loss (g/m^2)	Rate of loss (g/m^2/year)
Behind steel cassette over-cladding panel	60	0.50	0.10
	128	1.04	0.10

Note:
All coatings are non-chromated
Data averaged over at least two specimens for each exposure time
Measurements of zinc loss are for two surfaces

Figure 3.12 *Galvanized steel coupons installed behind the steel cassette over-cladding panels in Edinburgh*

The corrosion rates of the coatings of the flat coupons behind the cassette panel over-cladding system are less than those of the L-shaped coupons behind the composite panel system. The different corrosion rates can be explained by the different shaped coupons and possible differences in the ventilation and moisture penetration characteristics of the two over-cladding systems.

3.6 Non-insulated over-cladding system in Port Talbot

The site for this study is on the Corus Port Talbot steelworks complex in South Wales, which is an aggressive industrial environment in a coastal location. A 3 m by 3 m test panel of a non-insulated over-cladding system was constructed on the west facing wall of an industrial building in December 1996, as shown in Figure 3.13. Flat, non-chromated, galvanized steel coupons were installed in the cold air cavity behind the over-cladding panels.

Corrosion was assessed by measuring the weight loss of the protective coating during the exposure period. The results of the study are shown in Table 3.6. Coupons were collected for analysis after exposure periods of 60 months and 128 months.

Figure 3.13 *Over-cladding panel on industrial site in Port Talbot*

Table 3.6 *Measured weight loss of the galvanized steel coupons installed in cold cavity behind over-cladding panels in Port Talbot*

Location of coupons	Exposure time (months)	Non-chromated HDG	
		Total loss (g/m^2)	Rate of loss ($g/m^2/year$)
Cold air cavity behind over-cladding panel	60	6.66	1.33
	128	10.18	0.95

Notes:
Values are averaged over at least two specimens for each exposure time and location
HDG is a hot-dipped galvanized zinc coating of 275 g/m^2
Measurements of zinc loss are for two surfaces

The corrosion rates of the coatings of the coupons in this study are significantly higher than those of the Edinburgh study (see Section 3.5). The different corrosion rates can be explained by the different environmental conditions and the different types of over-cladding system (Port Talbot has a cold air cavity).

3.7 Light steel modular houses in Yorkshire

The two semi-detached modular houses shown in Figure 3.14 were constructed by Britspace Modular Building System Ltd in 1998 on the Britspace site in Gilberdyke, East Yorkshire. Each house consists of four modules (approximate dimensions 8 m long x 2.4 m wide). The modules were constructed with one open side. One of the houses (House B shown on the left of Figure 3.14) is fully furnished with carpets and furniture, while the other one (House A) only has plasterboard wall lining in place. The roof space was fully accessible in both houses. No over-site membrane was used but the undersides of the modules were insulated.

Figure 3.14 *Light steel modular houses in Yorkshire*

In May 2001, steel coupons were placed in accessible areas of both houses. The coupons were chromated hot-dipped galvanized. In January 2008, several of the coupons were collected and analysed for loss of coating. The results are shown in Table 3.7.

Table 3.7 *Measured weight loss of the galvanized steel coupons installed in a light steel modular house in Yorkshire*

Location of coupons		Exposure time (months)	Chromated HDG	
			Total loss (g/m^2)	Rate of loss (g/m^2/year)
House A:	ground floor level between modules	81	6.90	1.03
	first floor level	81	0.79	0.12
	in walls below windows	81	4.12	0.61
	in roof	81	1.00	0.15
House B:	in roof	81	0.89	0.13

Notes:
Values are averaged over at least two specimens for each location
HDG is a hot-dipped galvanized zinc coating of 275 g/m^2
Measurements of zinc loss are for two surfaces

The corrosion rates from this study are generally comparable with the results from the Ullenwood study (Section 3.3) and the Oxford Brookes study (Section 3.4). The corrosion rate at the ground floor level could be reduced by the provision of an over site membrane.

3.8 Non-insulated over-cladding system in Portugal

This study investigates the performance of hot-dipped galvanized steel coupons installed on a site within the campus of the Lisbon Technical University, Portugal. The site for this study is classed as a relatively hot coastal environment.

The location for the steel coupons was in a cold air cavity behind over-cladding panels (see Figure 3.15). The panels were constructed on the west facing wall of the Materials Science Department laboratory in January 1997.

Corrosion was assessed by measuring the weight loss of the protective coating during the exposure period. The results of the study are shown in Table 3.8. Coupons were collected for analysis after exposure periods of 60 months and 123 months.

Figure 3.15 *Coupons in cold cavity behind the uninsulated steel over-cladding system in Lisbon, Portugal*

Table 3.8 *Measured weight loss of the galvanized steel coupons installed in two locations in Lisbon, Portugal*

Location of coupons	Exposure time (months)	Non-chromated HDG	
		Total loss (g/m²)	Rate of loss (g/m²/year)
Cold air cavity behind over-cladding panels	60	1.61	0.32
	123	2.22	0.22

Notes:
Values are averaged over at least two specimens for each exposure time and location
HDG is a hot-dipped galvanized zinc coating of 275 g/m^2
Measurements of zinc loss are for two surfaces

Over the 123 month exposure period the average rate of loss for the hot-dipped galvanising behind the over-cladding panel was 0.22 g/m^2/yr.

3.9 Non-insulated over-cladding system in Finland

This study investigates the performance of hot-dipped galvanized steel coupons installed in several locations in Raahe and Hameenlinna, both in Finland.

Raahe is situated in the mid west of Finland. The steel coupons were located in two buildings that were refurbished in 1996 with a steel cold cavity over-cladding system. Coupons were placed in four locations around the buildings; behind the over-cladding panels on the north, south and west facing walls and in the insulated loft space.

Hameenlinna is an inland location in the south of Finland. The steel coupons were located behind over-cladding panels on a south east facing wall (see Figure 3.16) and in an insulated loft space.

Figure 3.16 *Coupons in cold cavity behind over-cladding system in Hameenlinna, Finland*

The results of the study are shown in Table 3.9 for Raahe and Table 3.10 for Hameenlinna.

Table 3.9 *Measured weight loss of the galvanized steel coupons installed in four locations in Raahe, Finland*

Location of coupons	Exposure time (months)	Non-chromated HDG	
		Total loss (g/m^2)	Rate of loss ($g/m^2/year$)
In warm loft space	60	0.36	0.07
	121	0.61	0.06
In cold cavity (N) behind over-cladding panel	60	0.57	0.11
	121	1.10	0.11
In cold cavity (S) behind over-cladding panel	60	0.57	0.11
	121	0.68	0.07
In cold cavity (W) behind over-cladding panel	60	0.70	0.14
	121	1.18	0.12

Notes:
Values are averaged over at least two specimens for each exposure time and location
HDG is a hot-dipped galvanized zinc coating of 275 g/m^2
Measurements of zinc loss are for two surfaces

Table 3.10 *Measured weight loss of the galvanized steel coupons installed in two locations in Hameenlinna, Finland*

Location of coupons	Exposure time (months)	Non-chromated HDG	
		Total loss (g/m^2)	Rate of loss ($g/m^2/year$)
In warm loft space	115	0.65	0.07
In cold cavity behind over-cladding panel	60	1.80	0.36
	115	1.34	0.14

Notes:
Values are averaged over at least two specimens for each exposure time and location
HDG is a hot-dipped galvanized zinc coating of 275 g/m^2
Measurements of zinc loss are for two surfaces

The results show that the facing direction of the over-cladding panel causes only minor differences in the rate of corrosion. The corrosion rates in the Raahe loft and the Hameenlinna loft are almost identical.

3.10 Japanese housing study

The Nippon Steel Corporation[18] 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. Therefore, 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 to 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 to 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.

4 CONCLUSIONS FROM CASE STUDIES

4.1 General

The rates of zinc loss on galvanized steel coupons in dry environments are very low and it has been observed that the rate of zinc loss reduces with time. This is because a zinc oxide layer forms on the surface and protects the zinc beneath.

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

- The rate of zinc loss with time is assumed to be linear and is taken as the rate of loss for the longest exposure time for which data is available. (This is a conservative extrapolation of the data.)
- A loss of 50% of the total zinc coating is assumed to 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, it has been assumed 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 for Category A components is estimated from:

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

For members or components that are fully exposed and can be inspected and repaired (e.g. purlins) a less conservative method has been used to predict design life. In this case, an 80% loss of zinc is taken to represent the design life (see Category B in Section 2.5). Therefore the design life is given by:

$$\text{Design life} = 0.40 \times \frac{\text{Weight of zinc coating}}{\text{Average rate of zinc loss}} \qquad (4)$$

Note: The weight of zinc coating is expressed as the total weight (i.e. 275 g/m^2 for Z275 specification); the rate of zinc loss is the weight loss summed over both faces.

4.2 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.

From the data presented in Section 3, the average rate of zinc loss of the components in warm frame applications does not exceed 0.25 g/m^2/year. By applying Equation 3 for the standard Z275 galvanized coating used in light steel framing, it follows that the design life is at least 250 years.

Data has not been specifically collected for 'warm frame' infill external walls in multi-storey buildings. However, the conditions can be considered to be similar to light steel load bearing walls. Therefore, the design life for light steel frames in infill external walls is predicted to be 250 years.

4.3 Roof space of houses

The roof space of houses is generally considered to represent a more severe environment than a warm frame wall application. However, from the data presented in Section 3, the average rate of zinc loss in domestic loft environments was very low and does not exceed 0.15 g/m^2/year (which is actually less than measured for warm frame wall applications).

Equation 3 predicts a design life of over 450 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:

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

These predictions assume that the integrity of the roof is not impaired, regular maintenance is carried out and that leaks are prevented.

4.4 Suspended ground floors

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

Data presented in Section 3 for uninsulated floors shows that the zinc loss was 1.22 g/m^2/year when no over-site membrane was provided (Section 3.3) and 0.20 g/m^2/year when an over-site membrane was provided (Section 3.4).

Based on these rates Equation 3 predicts a design life of 56 years for uninsulated floors without an over-site membrane and 340 years for uninsulated floors with an over-site membrane.

To allow for the many unknowns, it is considered that the design life should be taken as:

- 50 years for uninsulated floors without an over-site membrane
- 100 years for uninsulated floors with an over-site membrane.

The exposure severity can be reduced by using an external insulation layer beneath the floor, leading to increased design life.

These design life predictions assume that leaks from outside or inside the building envelope are prevented, the air below the floor is adequately ventilated (see guidance in SCI-P301[4]), steel is not in direct contact with soil and steel is properly protected from other potential sources of moisture.

4.5 Over-cladding applications

The light steel sub-frames to over-cladding systems are subject to variable conditions, depending on the exposure and type of cladding that is used.

From the data presented in Section 3, the average rate of zinc loss of the components in the light steel sub-frames of over-cladding applications does not exceed 0.43 g/m^2/year (excluding the result from Section 3.6 which was an extreme condition being an industrial coastal location). By applying Equation 3 for Z275 galvanized components, the design life prediction is 160 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 sub-frame members. If members are more exposed at the joints in the cladding, they should be additionally protected where they are subject to prolonged moisture.

4.6 Purlins and other roof members

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. Assuming that the members are exposed for inspection, Equation 4 may be applied. For Z275 galvanizing, the design life prediction is 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.

Further design guidance on the use of galvanized steel in exposed or external environments is given in BS EN 14713[9].

4.7 Summary of design life predictions

The design life predictions for galvanized steel in common applications in buildings are summarised in Table 4.1.

Table 4.1 *Design life predictions for galvanized steel*

Product application	Environmental conditions	Predicted design life
Walls and floors in warm frame applications	No risk of water ingress or condensation	250 years
Non-load bearing stud partitions	Warm internal environment and no risk of water ingress	250 years
Infill external walls in multi-storey buildings	Warm frame and no risk of water ingress	250 years
Roof structures (insulated)	Low risk of condensation	200 years
Suspended ground floors (with over-site membrane)	Low risk of water ingress; some risk of condensation	100 years
Roof structures (uninsulated)	Some risk of condensation	100 years
Purlins and side rails supporting metal cladding	Low risk of condensation; some dust and pollution	60 years
Sub-frames to over-cladding panels	Low risk of water ingress; some risk of condensation	60 years
Suspended ground floors (without over-site membrane)	Low risk of water ingress; higher risk of condensation	50 years

Note: All values are for Z275 (The weight of zinc coating = 275 g/m^2)

5 RECOMMENDATIONS FOR LONG DESIGN LIFE

5.1 Light steel framing in housing

General detailing requirements for light steel framing are provided in SCI publication P301[4].

The following recommendations are given to ensure a long design life in the use of light steel framing in housing:

- Provide a warm frame construction by placing the majority of the insulation on the external face of the light steel frame walls. 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 may be carried out in accordance with Appendix D of BS 5250[19]. A general recommendation is that at least 50% of the thermal resistance is provided outside the steel (to preserve the warm frame).
- In areas of potentially high humidity (e.g. bathrooms), provide a vapour control layer between the plasterboard and the light steel framing. Vapour control plasterboard or a separate polythene layer may be used to provide the vapour control. In living areas it is generally not necessary to provide an additional vapour barrier on the warm side of the light steel wall, as the inner layer of the plasterboard is suitable for this purpose.
- Provide drain holes in the bottom track of light steel walls to prevent any collection of water
- Provide a nominal 50 mm cavity between the light steel frame and external brickwork cladding, to minimise potential bridging of the cavity by mortar droppings and to allow for ventilation. In practice, taking into account construction tolerances, this cavity may reduce to 40 mm but should not be less than 40 mm.
- Provide a water resistant barrier on the exterior of the wall studs. Closed cell insulation boards provide this function. It is recommended to tape over the joints in the insulation, this also improves the air-tightness.
- A warm roof construction is preferred as the loft space will not be subject to condensation and is more air-tight.
- Joists used in internal floors, or over enclosed basements, or not directly connected to exterior brickwork, are protected from aggressive environments. Therefore, no further protection is required.
- For joists that attach directly to concrete or an exterior wall, provide a damp proof course below the joists, and some other suitable protection (e.g. bituminous) where the joists are in contact with the wall.
- At the supports of floor joists or decking in suspended ground floors, an additional bituminous coating and a damp proof course should be provided.

- For suspended ground floors constructed from light steel floor joists or metal decking, an over-site membrane should be provided, the void below the floor should be ventilated and the steel elements should not be in contact with soil or moisture from the ground.
- Particular attention must be paid to the detailing at window openings, door openings, floor and ceiling levels to prevent water ingress, ensure that water is effectively shed to the outer leaf of the wall and to avoid gaps in the insulation.

5.2 Other applications

The various conditions where galvanized steel sections are used in new construction and in renovation and the special measures required to ensure good performance in these applications are summarised in Table 5.1.

5.3 Measures to control damage on site

The following precautions should be taken to protect steel during both transport and storage to prevent damage and corrosion:

- Storage should be indoors or under cover and preferably in a clean, dry area.
- Always stack the packs on metal or wooden skids to keep them from direct contact with the ground.
- Where possible, do not leave uncovered sections or sheet stacks lying in the open. Store them under cover and away from open doorways.
- Use a purpose-made steel racking system to store the wall frames prior to their installation.
- Lift the wall frames directly from the lorry into position, which also reduces the risk of damage.

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

1. Erect a simple scaffold 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.
2. Store off the ground and on a slope so that any rain penetrating the cover will drain away.
3. Inspect the storage site regularly to ensure that, despite these precautions, the steel has not become wet.
4. Alternatively, use a steel stillage to stack the elements vertically rather than horizontally.

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

Table 5.1 *Good practice to ensure durability in new and existing construction*

Applications	Environmental conditions		Special measures
External walls	Warm:	Properly insulated and ventilated	No special measures required
	Cold:	Uninsulated, some risk of condensation	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 Note 1 for further protection
Roofs	Warm:	Properly insulated and ventilated	No special precautions needed
	Cold:	Uninsulated, some risk of condensation	Provide proper ventilation. Over-roofing improves the life of an existing flat roof
Steel lintels	Wet:	Potential water ingress from cracks in brickwork	Use thicker grade of zinc coating. See Note 1 for further protection. Also see BS 845-2[16]
	Dry:	No water ingress, properly drained	No special measures required
Infill walls for multi-storey buildings	Warm:	Properly insulated and ventilated	No special precautions needed provided cladding is external to the primary structure
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
Contact with other metals	Bimetallic corrosion of dissimilar metals should be avoided by using inert separators, especially between the fixings and cladding.		
Contact with other materials	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).		

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.

5.4 Remedial actions

Guidance on the remedial actions that can be taken to address white rust deposits and other forms of discolouration, based on the information in White rust in galvanized steel[20], is given in Table 5.2.

Table 5.2 *Surface discolouration of galvanized steel, and remedies[20]*

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 areas 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.
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.

6 OVERALL CONCLUSIONS

Galvanized steel components are used in a wide range of building applications. In housing and residential buildings, galvanized sections with a Z275 coating are used to create the primary framework, which is contained within the building envelope, in 'warm frame' construction.

The overall 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.

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.

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 sub-frames used in over-cladding applications can achieve a design life of 60 years, when properly detailed to avoid water ingress.

In suspended composite ground floors, the rate of zinc loss is consistent with a design life of over 100 years, provided that an over-site membrane is provided, the void below the floor is ventilated and the steel elements are not in contact with soil or moisture from the ground.

The following practices are necessary to ensure adequate durability of the galvanized steel sections:

- 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.

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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