BUILDING RENOVATION USING LIGHT STEEL FRAMING

Summary

Renovation is an important social and economic requirement and is an increasingly important part of the UK construction industry. The use of light steel framing has found a niche market in this sector, particularly in extensions and adaptation of buildings. Light steel framing comprises thin galvanized steel sections. This paper reviews recent applications of light steel framing in over-roofing and over-cladding of existing buildings, in new internal fit-out for building conversions, and the use of modular construction to extend buildings horizontally or vertically.

Over-roofing is an interesting application because new habitable space can be created cost-effectively without over-loading the existing structure. Over-cladding creates a new façade to an existing building. Building physics tests have shown that insulated external panels can be designed to offer 'trickle' ventilation to reduce the risk of condensation behind the new cladding whilst maintaining effective insulation. Modular construction concerns the use of pre-fabricated volumetric units as bathrooms / toilets, stairs and balconies, which is a well established technology in Scandinavia.

Economic assessments have shown that the renovation work can be self-financing in terms of energy savings and rental income over a 20 year period.

Introduction

Building renovation, repair and maintenance accounts for 50% of the output of the construction industry, and much of this work concerns the major renovation of buildings. There are many aspects to renovation in which the basic structure is retained, and the building is adapted to its new use. The different forms of renovation include:

- conversion of buildings for change of use or occupancy
- addition of new pitched roofs to eliminate water penetration and to provide new habitable space
- addition of over-cladding, windows and other facilities to improve appearance and to reduce heat loss through the existing façade
- extensions to buildings, including new facilities such as toilets, stairs, lifts etc.
- strengthening or repair of the existing structure and building fabric to extend its life, or increase its load capacity.

Light steel framing is increasingly used in new construction and in renovation. Its basic components are cold formed galvanized steel sections of typically C or Z shape (to BS EN 10327)[1], which are cold rolled from strip steel of 1.2 to 3.2 mm thickness. Typical member sizes are 75 to 300 mm depth.

'Light steel' implies lightweight, and differentiates these products from hot rolled steel sections which are more typical of primary structural frames. Typical light steel sections weigh 2 to 5 kg/m, and are easily handled on site. Design of these steel sections (also termed 'cold formed' or 'light gauge') is presented in BS 5950 Part 5[2] and EN1993-3. Their slenderness means that control of local and member buckling, local web crushing and connection design are important structural considerations. Member design tables are generally provided by the manufacturers.

In the context of building renovation, the main applications of light steel framing and other steel components are:

- new internal separating walls and partitions, which are required to have good acoustic and fire resistance, but must be lightweight
- new infill walls to support new cladding, or alternatively, over-cladding of existing façades using light steel sub-frames which support a range of lightweight cladding materials

- over-roofing of existing flat roofs, often with the creation of new habitable space
- new modular units used to extend buildings or to provide new toilet or bathroom units, and external lifts or stairs
- new mezzanine floors in buildings which have suitable floor to ceiling height.

Examples of these different applications are presented in Figure 1 to Figure 3. There is an important market in the conversion of redundant office blocks into apartments, which includes many of the above construction features. Similarly, renovating poor quality concrete panel buildings of the 1960's and 70's is an increasingly serious requirement for many public authorities. The characteristics of the construction methods which are sought in renovation applications are:

- speed of construction on site through offsite pre-assembly of major components, where appropriate
- lightweight to minimise loading on, or strengthening of, the existing structure
- long design life (730 years) and ease of maintenance and replacement
- good in-service performance, such as acoustic and thermal insulation and robustness to damage
- good fire resistance (i.e. non-combustible construction)
- minimum disruption by the construction activities and by aspects such as deliveries of materials.

This paper review recent advances in the use of light steel framing in the renovation sector, concentrating on the UK, but also introducing other European developments relevant to this sector.

Figure 1 *Over-roofing of hospital building using long span Capella roof trusses from Kingspan*

Figure 2 *Roof-top extension of an existing building at Plymouth University*

Figure 3 *Roof-top extension of an existing building in Rotterdam*

Infill and Separating Walls

Infill walls are placed within a structural frame or concrete slab structure and are designed to support the cladding and to resist wind loading applied to it. Infill walls comprise C sections of typically 150 mm depth that span vertically between top and bottom tracks fixed directly to the concrete slab. Some vertical movement is allowed for the attachment to the top track. An example of light steel wall construction is shown in Figure 4.

Figure 4 *New light steel infill wall by Metsec for roof-top extension*

These walls are insulted externally, which is often supplemented by additional insulation placed between the vertical members (studs). On the internal face, a vapour barrier and one or two layers of fire resistant plasterboard is attached. Lightweight cladding can be attached through the insulation directly to these studs, but brickwork requires separate support from the primary structural frame or slab or from the foundations. Wall ties, placed in a separate vertical track and attached to the studs, provide lateral support to the brickwork.

Separating walls are internal walls between apartments, and are designed to provide suitable acoustic insulation and fire resistance. Generally, the detailing measures required to provide good acoustic insulation are also sufficient to achieve 60 minutes fire resistance[3]. Two layers of fire resistant plasterboard supported on resilient bars on either side, with insulating quilt between the studs, gives an airborne sound reduction of over 53 dB, which is required by Building Regulations Part E (including the low frequency connection factor).

The motivation for using infill and separating walls in light steel is related to their speed of assembly, lightweight (particularly in relation to local line loads on floors), good acoustic insulation, and ease of relocation or future modification. Important new markets are in apartment buildings, cinemas, and major hospitals where these benefits can be realised.

Over-roofing or Roof-top Extensions

'Over-roofing' is a terms used for the creation of a new roof structure to an existing building[4]. it takes three basic forms:

- 'cold roof' construction, in which a new pitched roof covers a flat or slightly pitched roof and the insulation is placed on the existing roof.
- 'warm roof' construction, in which a new, often steeply pitched roof is insulated and often provides a mansard shape for habitable use
- roof-top extensions of one or two habitable floors, using support from the existing structure.

The main reasons for over-roofing are the poor performance of the existing roof (such as water leakage) and the desire to utilize the space in the roof, for example, for communal use or as new apartments. The form the new roof construction depends largely on whether or not the space is intended for habitable use. In hotels and commercial buildings, the new roof can also hide unsightly service plant and lift housings. The value of the new space created can pay for all the renovation work (see economic assessment).

Light steel framing may be used in ‘over-roofing’ schemes in the following forms:

- closely spaced trusses spanning between façade walls
- widely spaced trusses spanning between façade walls and supporting purlins between them
- portal frames or other moment-resisting structures supported on perimeter columns
- lightweight steel structure supported by a grillage of steel beams.

The trusses may take the form of simple pitched trusses (normally ‘Fink’ or ‘Pratt’ trusses) or mansard-type trusses, creating deeper useable space. The ‘Capella’ system by Kingspan, shown in Figure 5, uses bolted C and Σ sections to offer a versatile system for variable roof slopes.

Figure 5 *Capella system of over-roofing using C and Z sections*

Portal frames provide more useable space, but have the disadvantage of requiring horizontal ties or some other restraint at their base which may be affected by the capabilities of the existing structure. For this reason, portal frames used in over-roofing schemes should generally be supported on the existing columns of steel or concrete framed structures. The ‘Swagebeam’ system by Ayrshire Framing has been specifically developed to achieve moment connections through their swaged ends when bolted together. This system can be bolted together easily on site to minimize craneage.

Pre-fabricated trusses can be lifted into place and are supported on the existing load-bearing walls or columns. The space between these trusses can be utilized to cover roof-mounted plant, and to provide for habitable space. Trusses can be also designed to incorporate door openings. Purlins spanning between the widely spaced trusses are typical of conventional roof construction. Roof sheeting, tiling battens and tiles may be attached to create a more traditional external appearance.

The construction of new apartments on the top of the former Shell Downstream Building demonstrated the use of ‘stick-built’ on-site light steel construction for this 2 storey roof top extension. The apartments are built to a high standard of acoustic insulation in the separating walls, shown in Figure 4.

The light steel structure of the building in Figure 3 in Rotterdam is shown in Figure 6.

Figure 6 *Light steel framework of roof-top extension in Rotterdam*

Over-cladding

'Over-cladding' is defined as the attachment of new cladding directly over an existing façade[5], and is differentiated from 're-cladding' in which the existing cladding is replaced. Over-cladding is carried out in order to:

- reduce the heat losses through the façade and to meet modern thermal regulations
- improve the appearance of the building
- arrest the deterioration of the existing structure or façade, including water leakage
- minimise disruption to the occupants during the renovation process.

Over-cladding can use a variety of materials, including composite (sandwich panels) or metallic cassette panels, as shown in Figure 7. Insulation is provided behind the new cladding and may be attached to the existing wall with suitable weather protection.

Over-cladding often involves use of a sub-frame which is attached either directly to the existing façade, as shown in Figure 8, or preferably to the existing floors or primary structure which avoids attachment to a potentially weak existing facia. In the second case, the sub-frame must be much more robust and longer spanning, which lends itself to the use of light steel framing. Storey high sub-frames can be created. This frame and its attachments requires some form of adjustment for site tolerances, and also the irregularity of the existing façade

Figure 7 *Over-cladding using horizontally orientated metallic panels*

Figure 8 *Over-cladding using light steel cassettes in Finland*

A large number of buildings have been over-clad in the UK and in Scandinavia using a variety of metallic cladding systems, and some examples are shown in Figure 6 and Figure 7. Harrison[6] reviewed various case examples for large concrete panel buildings. Often over-cladding is combined with over-roofing as part of a comprehensive renovation strategy. New windows are also provided so that the overall savings in energy use by the occupants are dramatically reduced.

A prototype over-cladding system using composite panels spanning vertically between sub-frames, which are attached to concrete slabs, was developed in research at Imperial College, London. A 5 m × 6.3 m composite panel by Kingspan has been subject to exposure trials at Edinburgh University for over 4 years. The completed panel is shown in Figure 9 It was found that the environmental conditions in the cavity behind the new façade do not lead to a risk of condensation, and that the small air movement is such as not to significantly affect the insulating effect of the external composite panels (see later). The heat losses through the existing façade are reduced by over 50%.

Figure 9 *Edinburgh University over-cladding test*

Other over-cladding systems using light steel framing include profiled sheeting of various forms with insulation behind, or large cassette panels supported on sub-frames. Generally over-cladding systems are designed on 'rain screen' principles[7]. The light steel sub-frames can be perforated, to reduce 'cold-bridging' through them, but this form of local heat loss is not usually significant in terms of overall energy efficiency.

A representation of a typical concrete building with new cladding stairs and balconies is shown in Figure 10.

Figure 10 *Representation of over-cladding and new external lifts and stairs*

Modular Units in Renovation

Buildings may be extended easily using modular or 'volumetric' units which are self-supporting vertically, but which are supported laterally by the existing structure. The modular units are pre-fabricated and fully fitted out before being transported to site. Modules are generally less than 3.5 m wide so that they can be transported without special escort and are easily lifted into place. Cladding can be pre-attached, or can be installed conventionally on site.

Examples of the use of modular construction in renovation include:

- new external toilet and bathroom units – see Figure 11
- new balconies and access ways
- new lifts and stairs
- roof-top extensions to create new rooms.

The use of modular units in renovation applications is most well established in Scandinavia, where an efficient large-scale factory production is allied to speed of construction, and a short 'weather-window'. However, interest in modular construction is increasing in the UK, and recent applications include medium-sized hotels and social housing projects[8]. A particular niche market is in extensions to existing hotels, where speed of construction and minimum disruption to the hotel operation are the main benefits. New bathroom and toilet modules may also be used inside existing buildings by sliding them into position on the floors.

Figure 11 *Toilet module in building extension in Finland (by Ruukki)*

An example of the use of modular construction in a rooftop extension to create new study bedrooms in a student residence in Finland is illustrated in Figure 12. New modular units can also be included as part of a comprehensive over-cladding and renovation scheme, as illustrated in Figure 2. The light steel structure of the open-sided modules in this project is shown in Figure 13. In this case, the floor and roof members of the 6 m long modules are orientated longitudinally.

Figure 12 *Modular units in roof-top extension in Finland*

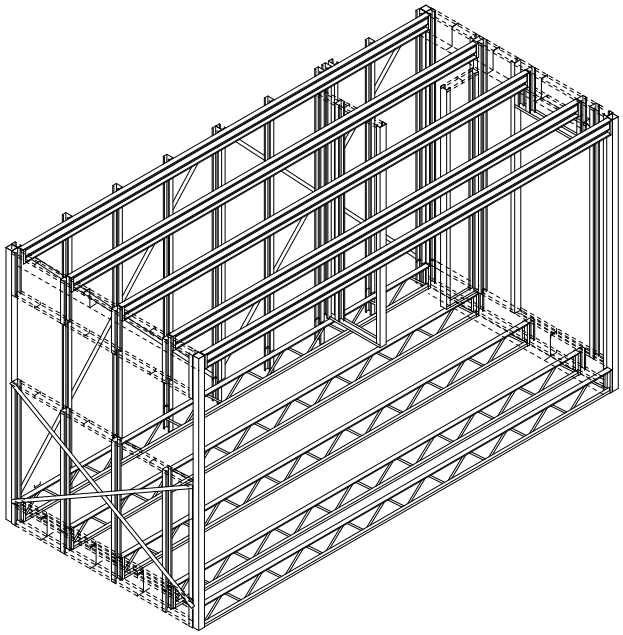

Figure 13 *Structural components of open sided modules used in the roof-top extension at Plymouth*

Economic Assessment of Over-roofing and Over-cladding

A full economic assessment of over-roofing and / or over-cladding savings must take into account the following annual savings and income, in addition to the broad social and environmental benefits. The readily quantifiable financial benefits are:

- savings in heating bills for both the occupants and owner
- increased rental charges due to an improved internal and external environment
- increased revenue (or sales) from the creation of new habitable space or additional facilities
- reduced maintenance and repair costs of the existing roof or façade.

Other demonstrable savings of these renovation projects, in comparison to the alternative of demolition and re-building are the:

- cost of having to re-house the occupants temporarily
- extra cost and disruption of demolition and re-building in terms of site infrastructure, etc.
- time delays required by demolition and re-building

The broad social and environmental benefits are:

- less energy use in service and also in the renovation process
- better comfort and quality of life for the occupants
- reduced CO_2 emissions in terms of the construction process and long term energy use
- less noise during renovation in comparison to demolition and new build
- much less waste and land-fill charges
- less additional local road traffic and environmental impact
- improvement to the urban landscape.

An economic assessment has been made of the over-roofing and over-cladding of a typical 12 storey high-rise building in West London consisting of 96 two bedroom apartments. Over-roofing creates eight new apartments and over-cladding of the whole façade (including new windows) reduces heat losses by over 70%.

Direct annual fuel cost savings of about £190 per apartment were estimated, which is equivalent to over £18,000 per annum for the whole building. Assuming a 2% increase in the real cost of energy, the present value of the fuel cost savings over 20 years amount to £246,000 or £36/m^2 of existing floor area.

However, additional annual revenue is generated by reduced maintenance, increased rental revenue from existing apartments and rental revenue from the new roof-top apartments (£80/m^2 of new floor area per annum). Thus, total savings (including fuel cost savings) have been estimated to be in excess of £94,000 per annum, with a present value over 20 years of nearly £1.3 million, of £173/m^2 of total floor area.

The cost of the over-roofing scheme is taken as £800/m^2 of new floor area, and the cost of the over-cladding scheme is taken as £150/m^2 façade area, which are typical costs of recent projects. This gives a total cost of the renovation scheme of £1 million, which is equivalent to £135 m^2 of total floor area.

It follows that the renovation scheme is self-financing over a 20 year period based on the easily quantifiable benefits. Inclusion of other environmental benefits, as listed above, would make the argument for renovation even more compelling.

Added to these economic benefits is the predicted reduction in CO_2 emissions of 513 tonnes per year. Furthermore, these benefits will continue long after the ‘pay-back’ period.

Design Life

The standard thickness of zinc coating in galvanized strip steel is 275g/m^2 and the design life of galvanized steel components is very long (700 years) in a warm dry environment. In conditions which may lead to periodic condensation, the design life exceeds 60 years, provided that water is able to evaporate and does not run over the surface. This is because hydrated zinc products will protect the steel surface from further zinc loss unless washed away.

In a ‘cold roof’ or over-cladding application, some longer term moisture presence may be expected. However, data collected by Corus and SCI shows that the ‘time of wetness’ is still relatively short in these applications. In over-cladding systems, trickle ventilation allows for pressure equalisation behind the new façade and prevents ingress of direct rain and allows for drying out, as observed in the Edinburgh University prototype over-cladding tests which have now been in place for 13 years in relatively exposed conditions. A typical thermal profile is presented in Figure 14, which shown the thermal ‘buffer’ effect of the over-cladding.

The design life of galvanized steel in over-cladding and over-roofing applications may be estimated as at least 60 years, and very long in internal ‘warm frame’ applications. The over-cladding elements may be replaced, if damaged.

Conclusions

This paper reviews the application of light steel framing in the renovation sector. ‘Over-roofing’ is a particular niche market for which light steel framing is ideally suited. New habitable space can be created easily. ‘Over-cladding’ using light steel sub-frames and new cladding can lead to considerable energy savings to meet new thermal regulations, and reduce CO_2 emissions. Economic assessments have demonstrated that the complete renovation work can pay for itself in terms of energy savings and additional income over a 20 year period.

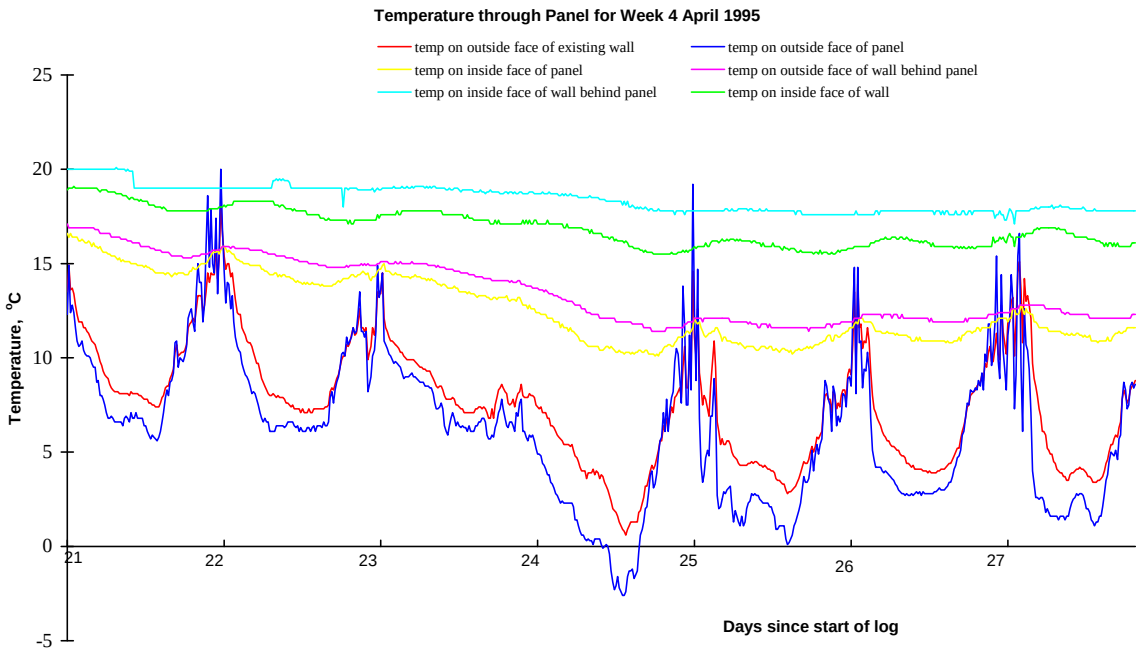

Figure 14 *Thermal performance of Edinburgh University over-cladding test*

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