WP 4.6: Design Guidance on Use of Light Steel Systems to Upgrade Roofs in Residential Buildings

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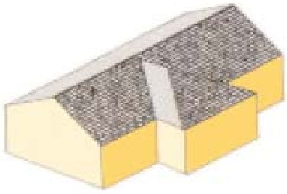
1. Introduction

Renovation of existing roofs to provide additional space is an important and expanding sector as it increases the building size without adding to its 'footprint'. The level of complexity of retro-fitting existing timber roofs to creating habitable roof depends on the type of roof structure, which is linked to the period when the building was built. This note provides a brief guiance for the refurbishment of roofs using light steel trusses and roofing systems.

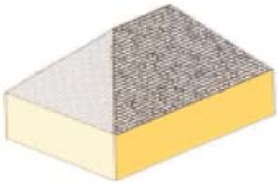
1.1 Roof typologies

Traditionally, residential roof structures are constructed in timber and the methods of fixings are nails, screws and bolts. Roof shapes are either near flat or pitched. The majority of buildings have pitched roofs with sides either designed as gable end or hipped (see below).

'T' Intersection roof with gable side



Overlaid hip roof with gable side



Hipped roof

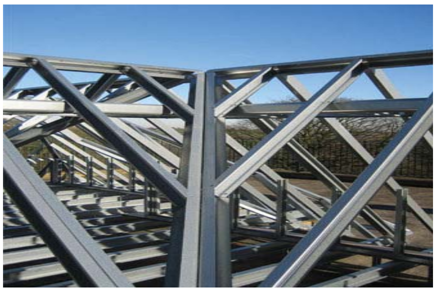
Figure 1: Different types of roofing systems

1.2 Flat roof conversion

Two typical refurbishment options are 'Flat-to-pitched' conversion or Flat to 'Room-in-the roof'. There are a few lightweight cold-formed steel systems on the market but they are not as popular as timber solutions. There are major opportunities for prefabricated lightweight steel solutions for this application.

Flat to pitch conversion using lightweight steel

Prefabricated lightweight steel system



Flat to room in the roof conversion using lightweight steel

Figure 2: Steel systems used in over-roofing of flat roofs

Over the years, more than one million roofs have been converted to create a room-in-the-roof. Availability of headroom is a major consideration when converting loft space. The majority of the existing roofs can provide the minimum of 2.3 m headroom height required to be suitable for conversion. Dormer windows are widely used to increase the width of the room and available headroom.

1.3 Pitched roofs conversion

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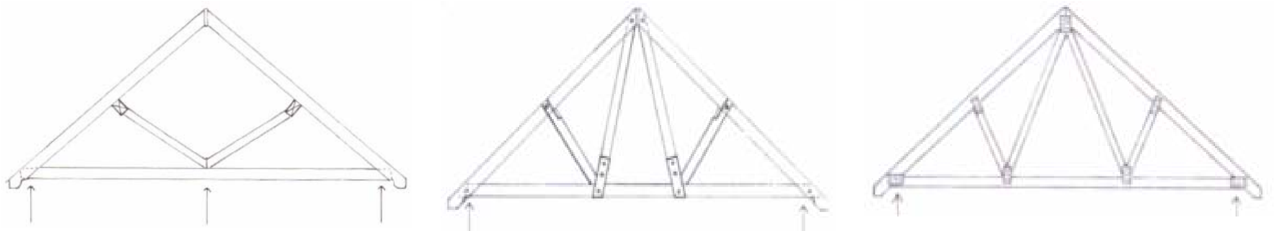


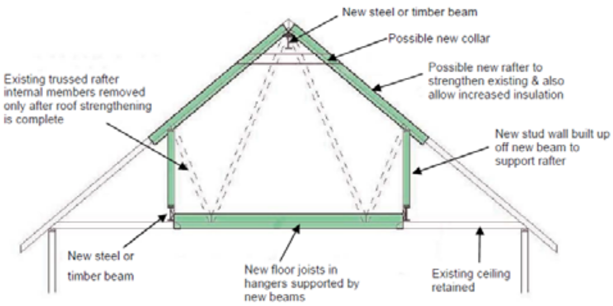
Strutted purlins | Trada trusses | Trussed rafters

Figure 3: Traditional timber roof trusses

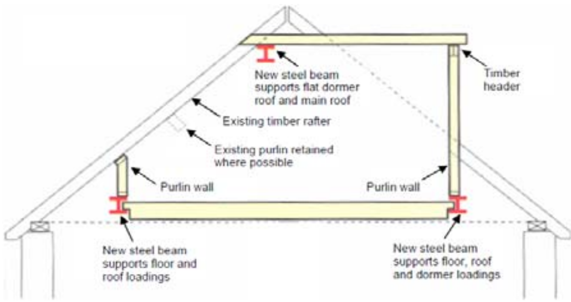
The generic structural alterations to these roof types to create 'room-in-the-roof' space includes installation of:

- New beams spanning from gable to gable/party wall to carry new floor load,
- New floor joists between the existing joists,
- Stud wall on top of the beam to support part of the roof,
- New beams at the ridge level (or near the apex) spanning from gable to gable/party wall for long span rafters or large new dormer window (≥ 1.2 m) added,
- Collars depending on the span of the rafters,
- Removal of existing strutted, purlin or trussed internal members.

Traditionally, hot rolled steel beams are the preferred option despite the difficulty in installing the beams in available tight roof spaces. Sometimes the beam needs to be cut into 2 or 3 small beams, which are then bolted together. This makes the logistics of loft conversion very tedious. The use of lightweight cold-formed steel for this application may be a better option.



Typical structural modifications of Trussed rafters for habitable roof



Typical structural modifications of purlin roof with large dormer window

Figure 4: Illustration of steel systems to create new roof space

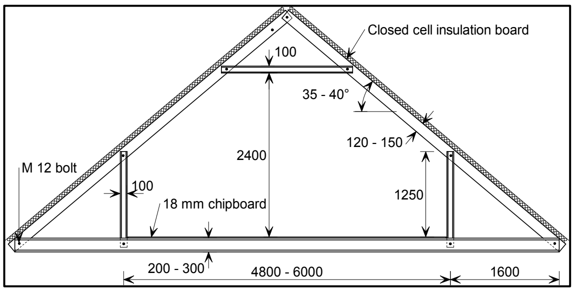
1.4 Lightweight steel roof: "Open roof"

The open roof system is based on the use of cold formed C or Z sections. The members are easy to assemble on site using 12 or 16 mm diameter bolts located in pre-punched holes (although screws would also be possible). The roof system can be easily varied to suit the required living space and window openings such as *Velux* type roof lights. The roof may be a "warm construction" where insulations are applied externally by closed cell insulation board to which counter-battens and battens are attached. Slotted or perforated C sections for the rafters may be advantageous for "cold roof construction", where mineral wool insulation is placed between the rafters.

1.4.1 Open roof: new build or flat to room-in-roof

The range of application of the open roof system and the recommended minimum sizes of the C sections are presented below.

The optimum design of the system is 8 m span, which is typical of 3 or 4 bedroom house.



Typical chord and rafter sizes for the open roof system

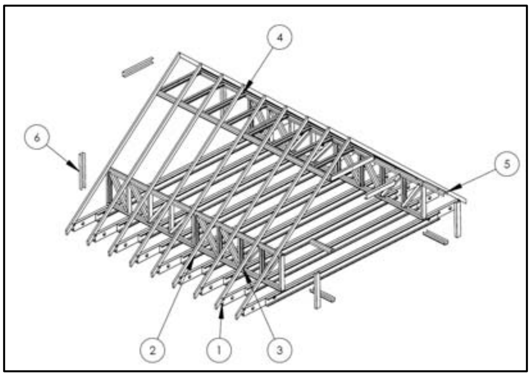
Span (m)	Roof Slope	Room Width (between verticals	Member Sizes		Approximate Steel Weight (kg/m²)
			Bottom chord	Rafter	
6	45^0	3.6 m	150 × 1.2C	100 × 1.2C	16
8	40^0	4.4 m	180 × 1.6C	125 × 1.6C	18
10	35^0	6.0 m	250 × 2.0C	150 × 1.6 C	24

1.4.2 Lightweight steel for retrofitting existing roof

Light steel open roofs based on 'retrofitting' of timber trusses may be of two basic forms:

- 'A frames' consisting of rafters and bottom chords to the existing trusses, strengthened using C sections. In this case, the roof trusses span between front and rear façades.
- Longitudinal lattice girders that support the existing timber rafters. In this case, new longitudinal trusses span between cross-walls or gable walls.

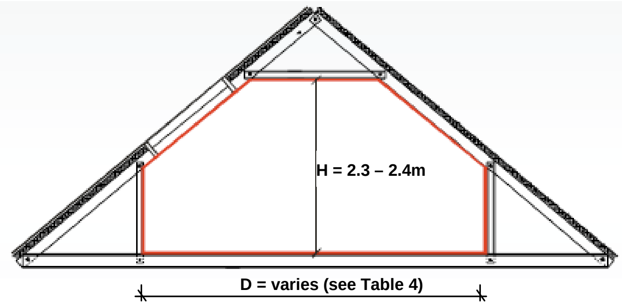
The practical use of open roof system is illustrated in the diagram. The existing timber members are strengthened in one direction by C sections (element 1) that are screwed to the timber floor joists , and in the other direction by longitudinal roof trusses (element 3) that are attached to the existing masonry end walls. In order to allow for geometrical inaccuracies, C sections (element 6) are fixed to the walls and then the trusses are fitted between them and screwed to them.



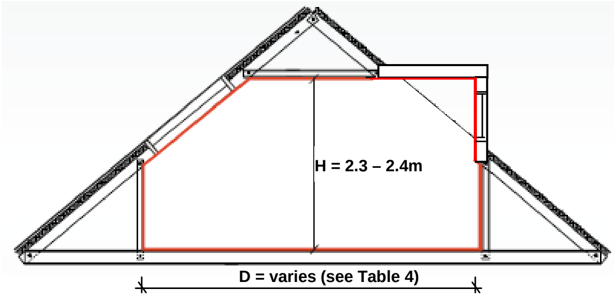
2. Key Design Considerations

2.1 Dimensional planning for room in the roof space

In the UK, there is no regulatory minimum headroom requirement for loft conversion. However, typical practices demands headroom (H) between 2.3 to 2.4m as illustrated below. Typically, dormer windows are used for shallow pitched roof to increase the width of the usable space as shown in (b).



a) Typical room in the roof conversion



b) Typical room in the roof conversion with dormer window

Figure 5: Illustration of space requirements in roof conversions

The available headroom height is a critical parameter to any loft conversion. Possible available headroom and room depth for a given roof pitch and span are presented below.

Available Headroom for Loft Conversion

Pitch \ Span	Available Headroom (A_h) m							
	5	6	7	8	9	10	11	12
30°	1.44	1.73	2.02	2.31	2.60	2.89	3.18	3.46
35°	1.75	2.10	2.45	2.80	3.15	3.50	3.85	4.20
40°	2.10	2.52	2.94	3.36	3.78	4.20	4.62	5.03
45°	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00

*Note

- Spans are measured between the wall plates.
- Available Height (A_h) is the maximum ceiling heights available beneath the ridge (apex of the roof)
- Approximately 400mm needs to be allowed for floor joists, ridge beam and finishings.
- No allowance has been made for raised collar ties

Not suitable as available headroom is limited

Possible But headroom ≤ 2.3 m after deduction of 400mm for floor joists, ridge beam and finishing

Suitable as headroom ≥ 2.3 m

Available Room Depth for Loft Conversion

Pitch \ Span	Available Room depth (d) m							
	5	6	7	8	9	10	11	12
30°	1.88	2.88	3.36	4.36	4.84	5.84	6.32	7.32
35°	2.43	3.43	4.0	5.00	5.57	6.57	7.14	8.14
40°	2.85	3.85	4.50	5.50	6.14	7.14	7.78	8.78
45°	3.20	4.20	4.90	5.90	6.60	7.60	8.30	9.30

Not suitable as available headroom is limited

Possible But headroom ≤ 2.3 m after deduction of 400mm for floor joists, ridge beam and finishing

Suitable as headroom ≥ 2.3 m

2.2 Structural considerations

The challenge of roof conversion is to find the safest means of transferring the heavier loads from the habitable roof space down to the existing foundations. The general idea is to transfer the additional loads from the new space onto the existing external walls. This is achieved by supporting new beam (or joists) supported on the external walls or party walls. However, where the existing internal walls are load bearing, the new beams or joists may be supported on these walls.

In most cases, with the exception of bungalows (single story building), the existing foundations are adequate to cope with the additional loading. Therefore, underpinning of existing foundation is normally not required. The general rule is that the additional load applied to the foundations should not exceed 20% of the original load.

In majority of buildings, the internal load bearing walls stop at the first floor and the existing roof structure spans between the outer walls to walls. Should there be a need to use the existing internal wall as load bearing, care must be taken to ensure that the existing foundation under this wall is adequate to carry additional load.

New beams to support the roof rafters and new floor joists are the essential part of loft conversion. Hot rolled steel beams and lightweight steel trusses may be used. Careful consideration must be given to the use of hot rolled section because of the difficulty in manoeuvring the beam in a very tight space available in the loft. Beams are normally sized to be 200mm longer than the actual span to provided 100mm bearing each side on the support wall. Steel plates or concrete padstones are generally required under the support beams to spread the load because the existing brick walls are normally weak. For example, brick walls built with lime mortar have a low comprehensive strength of about 0.21N/mm^2.

Party walls are normally built in a solid or block cavity wall. Care must be taken to ensure that:

- end of the support beams at 100mm do not extend beyond the mid line of the party walls.
- support beams do not bear into chimneys or the party wall between chimneys. Sometimes, to avoid penetrating into chimney breast, a new steel ridge beam is supported on a steel column.
- combustible materials e.g. timber are separated from a brick chimney breast by at least 40mm from the outer surface of the chimney (and 200mm from the flue itself).
- metal fixings such as joist hangers that contain combustible materials (e.g. timber joist) are positioned at least 50mm away from a flue.

Existing timber loft joists are relatively small section of 50 x 75 to100mm deep at 400 – 600mm centres. These are too weak to carry the new imposed floor loads arising from loft conversion. As a result, these are normally left in place to carry the ceiling load. New timber or lightweight cold form steel sections are installed between the existing joists to strengthen the existing joists. Existing timber rafter sizes are typically 50 x 75 to 125mm deep. These rafters should be strengthened by either pairs of joists either side of the timber sections, or installation of a steel beam to reduce the span of the timber sections.

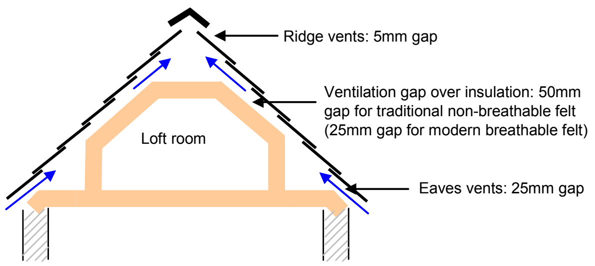
2.3 Roof insulation and condensation

'Warm roof' construction is the most effective method of preventing condensation, but is only applicable to a new roof, an existing flat roof conversion by over-roofing ,or where the existing roof tiles are removed and re-roofed. However, the latter may require planning permission because of alteration to the existing roof line.

Most loft conversions are 'cold roof', which involves upgrading the original roof from the inside. Typical practice involves adding insulation between and/or under the roof rafters. Measures to avoid condensation risk are necessary because the existing felt layer is a traditional non-breathable membrane. Condensation risk is avoided by either:

- provision of cross ventilation above the insulation layer on the cold side of the roof as shown in sketch (a).

- or the roof tiles could be stripped and the existing traditional non-breathable felt layer replaced with a vapour permeable layer (breather felt) as shown in sketch (b) below. The ventilation gap above the vapour permeable layer can be reduced to 25mm.



a) Cross ventilation of room-in-roof to avoid condensation risk

b) Between and under rafter insulation with modern breathable membrane

Figure 6: Ventilation strategies in over-roofing

2.4 Fire safety

Provision of means of escape and fire protection is required for a loft conversion. The following represent the common practices in compliance with the fire safety regulation:

- Staircase must discharge close to a door leading to an external safe place and not to another room.
- All doors openings and walls enclosing staircases must have at least 30 minutes fire resistance, with the exception of toilets and bathrooms doors.
- Mains powered interlinked smoke detectors are to be provided, with a minimum of one detector per level.
- If the building has a basement, its ceiling must have at least 30 minutes fire resistance and the basement is to be separated from the ground floor by fire resisting construction.
- The first floor ceiling should achieve at least 30 minutes fire resistance.
- Dormer cheeks within 1 metre of a boundary are to have at least 30 minutes fire resistance in both directions. The dormer roof is to have at least 30 minutes fire resistance.

2.5 Thermal performance

The up-grading of roofs has various effects on the thermal and energetic behaviour of a building. Depending on the characteristic of the renovation and the use of the building, the following aspects have to be considered:

- Heat transfer coefficient (U-Value) of the construction before/after renovation (including thermal bridges)
- Increasing compactness (additional floor space should add only a small amount to surface of building envelope)
- Control of over-heating (large surfaces exposed to solar irradiation combined with very little building mass)
- Air permeability (need to improve the air-tightness of the old and new roof structure)

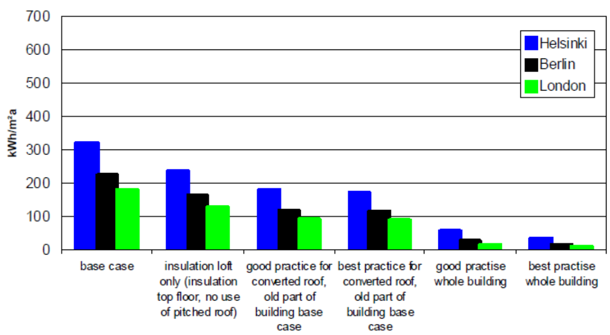
2.5.1 Thermal simulation

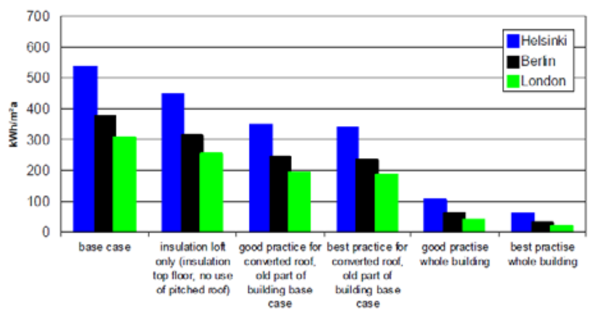
A series of thermal analysis of various building types in three different European locations (Helsinki, Berlin and London) have demonstrated that better insulated buildings achieve considerable energy, operational carbon and cost savings.

Data for thermal simulation and sample results are show below. The results show that the:

Element	Description	Base Case (before loft conversion)	Good practice (with loft conversion)	Best practice (with loft conversion)
		U-value (W/m²k)		
Pitched roof	Uninsulated timber roof	1.9	0.20	0.15
Loft floor	Timber joists, minimal insulation	0.85	0.25	0.2
External wall	Uninsulated solid block	2.1	0.30	0.15
First floor	Uninsulated timber floor	3.0	0.25	0.2
Ground floor	Uninsulated solid floor	0.45 – 0.7	0.25	0.2
Window	Partly double glazed	3.5	2.0	0.7
Window area (%)	Wooden frame window	12 -15%	12 -15%	12 -15%
Air-tightness	$m^3/(hm^2)$ @50Pa	15	10	3

- energy demand for the new habitable space in the roof is relatively small and depends on the quality of the upgrading ('good' or 'best' practice).
- energy losses of the existing part of the building are reduced due to reduced energy losses resulting from improved thermal performance of the roof.
- heating energy demand of the refurbished building with additional space is lower than of the base case and the the additional heating energy demand is negative.
- combination of additional space and retrofit of the existing building leads to a high energy saving potential.





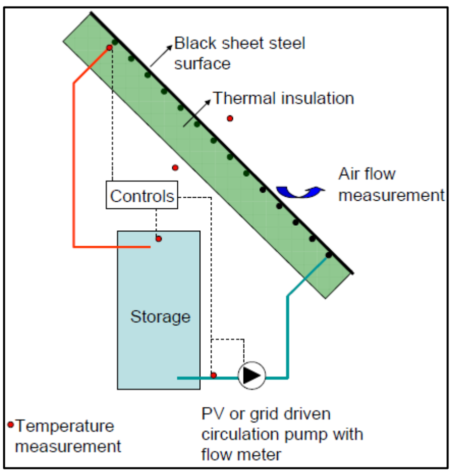
Heating energy demand - Mid-terrace house   Heating energy demand - Detached

Figure 7 Heating demand for oriiginal and renovated hosues in three climates

2.6 Renewable energy options

The integration of the renewable energy in the roof and façade as part of refurbishment regime to provide free electricity, heating and hot water is essential. Steel solutions for refurbishment are generally better suited to provide an integrated and multi-function roofs and facades systems. As part of this project, a host of renewable energy solutions that can be integrated in steel roof and façade systems investigated are:

- Roof mounted portable wind turbines
- Steel roof integrated solar PV system
- Stand-alone solar air heating system
- Solar integrated ventilation heating system
- Roof integrated solar water heat collector



Principle of roof integrated solar