Multi-storey, steel-framed buildings are much, typically 60%, lighter than equivalent concrete-frame buildings. This often leads to the myth that steel buildings cannot meet acoustic and vibration criteria.

The steel sector has extensive experience in the design of steel structures that comply with the strictest vibration and acoustic criteria. Comprehensive, detailed guidance and tools are available for designers to ensure that structural steel continues to deliver speed, cost and sustainability benefits without compromising vibration and acoustic performance.

## Floor vibrations

Floor vibrations refer to the oscillatory motion experienced by the building and its occupants, during the course of normal, day-to-day activities.

Vibrations occur in all structures and are mostly imperceptible. When performance specifications limit the vibration response of a building, the proposed structural layout can be easily checked by the designer.

For most multi-storey, office buildings, straightforward steel construction will meet the required vibration performance criteria without modification. For more vibration-sensitive applications, such as hospital operating theatres, more analysis may be needed and, if required, the steel frame can be stiffened.

The most common source of vibration that can cause nuisance in buildings is human activity, usually walking. Although small in magnitude, walking-induced vibrations can cause a nuisance to people working or living in the building.

Once constructed, it is difficult to modify an existing floor to reduce its susceptibility to vibration, as only major changes to the mass, stiffness or damping of the floor system will produce any perceptible reduction in vibration amplitudes. It is important therefore that the levels of acceptable vibration be established at the concept design stage.

Long-span applications, for which steel is the only structural option, have been found to offer excellent vibration damping, despite common preconceptions. This is because the stiffer beams and the large mass of the long-span floor plates, which participate in any motion, reduce the vibration response.

### Assessing floor vibrations

Generally, the vibration of floors is considered to be a serviceability issue, primarily related to the discomfort of building occupants or damage to sensitive equipment.

For slender floor structures, as made in steel or composite construction, serviceability criteria generally govern the design.

The motion of a vibrating system can be defined in terms of three parameters:

1. The frequency defines how quickly it vibrates.
2. The amplitude defines how much it vibrates.
3. The damping defines how long it vibrates.

Historically, vibration design has been limited to ensuring that the primary and secondary beam frequencies are independently, above a certain level, generally 4Hz. However this relatively simple requirement does not take account of all of the factors relevant to specific building types and uses, etc.

Today a number of simplified procedures have been developed to allow a structural engineer to analytically determine occupant acceptability of a proposed floor system.

Generally, the analytical procedures require the calculation of the first natural frequency of the floor system and either maximum amplitude, velocity, or acceleration for a reference excitation. An estimate of the damping in the floor system is also required.
in some instances. A human perceptibility scale is then used to determine if the floor system meets serviceability requirements.

Finite element modelling may be used to obtain the natural frequencies, modal masses and mode shapes of any shape of floor. This method is particularly useful for buildings with irregular grids or with onerous vibration requirements, e.g. hospitals. The method is more accurate and generally less conservative than hand calculation methods.

**Figure 1. Finite element modelling used to predict floor vibration response**

**Acceptable vibration limits**

Human perception to motion is usually related to acceleration levels rather than displacements and therefore vibration limits, or acceptable thresholds, are also expressed in terms of acceleration.

Current Standards quantify the magnitude of floor vibrations in terms of the acceleration of the floor; defined in terms of weighted, root-mean square (rms) acceleration. The acceptability of a floor is assessed by dividing the predicted acceleration by a baseline value to obtain a response factor, and checking that the calculated response factor is less than the appropriate multiplying factor given in the relevant Codes and other specialist guidance. The response factor target for office buildings is generally 8. Whereas the target in hospital operating theatres and wards would typically be 1 and 2 respectively.

If the floor response is found to be unacceptable during the design assessment, the designer can adjust the structural arrangement such that the vibration response is reduced to acceptable levels. Possible measures include increasing the mass, stiffness and damping of the floor, and relocating or reducing the length of corridors, etc.

A useful tool to enable designers to assess the dynamic response of a floor solution has been developed by SCI – see further information below.

**Acoustic performance**

Good acoustic performance is important in all multi-storey buildings, but is particularly important for residential buildings, schools and hospitals. In office buildings, the main considerations are external noise intrusion, internal noise and noise from building services.

**Sound**

The manner in which humans perceive sound governs the way it is measured and described. Two important characteristics of sound which humans can detect are:

- The level or loudness
- The pitch or frequency.

Sound levels and sound insulation, i.e. attenuation, values are expressed in decibels (dB), whilst pitch or frequency is expressed in Hertz (Hz).

In buildings, the most important elements affecting the acoustics are the walls and upper floors. The sound insulation properties of walls or floors vary with frequency and, as most sounds are a mixture of different frequencies, certain frequencies are likely to be attenuated more effectively than others by a given construction. Therefore, the sound reduction characteristics of walls and floors are measured at a number of different frequencies across the human hearing range.

There are two types of sound that should be considered in the acoustic design of buildings:

- Airborne sound
- Impact sound.

Airborne sound insulation is important for both walls and floors. The airborne sound insulation performance of building elements can be measured in the laboratory. The resulting value is the sound reduction index $R$.

Impact sound insulation is generally only relevant to floors. Laboratory testing involving a standard impact sound source, is used to derive the normalised impact sound pressure level $L_n$.

Building performance specifications usually set acoustic requirements in terms of $R$ and $L_n$.

**Sound paths**

To reduce the passage of sound into, out of, and around a building the construction details of the floors, walls and their junctions are key to its acoustic performance.

When a room is separated from another room, sound can travel either directly through the separating element (direct transmission) or around the separating element through adjacent building elements (flanking transmission). Sound insulation for both routes is controlled by the following three characteristics:

- Mass
- Isolation
- Sealing.

Direct transmission depends upon the properties of the separating wall or floor and can be estimated from laboratory measurements. Flanking
There are many different types and configurations of wall stud, insulation material and boarding available, each having different acoustic properties. By choosing the correct products and construction details, good acoustic performance can be achieved.

A range of steel solutions is available for internal, external and separating walls. An example of a separating wall detail is shown below comprising steel studs, mineral wool insulation and two layers of plasterboard on each face. The predicted sound reduction index (R) for this construction is 56 to 66dB.

Information, specific to different markets and building types, is available from product manufacturers and other sources. A useful acoustic performance prediction tool has been developed by SCI – see further information below.

Floors

Similarly for separating floors, the steel sector has developed a range of construction details to meet different levels of acoustic performance. Details and expected acoustic performance information, is available for all floor types commonly used in steel-framed buildings including:

- Composite floors on steel beams
- Precast concrete units on steel beams
- Light steel joists with boards
- Light steel truss with screed.

In addition to the floor structure, the floor and ceiling treatments are important in achieving the required acoustic performance.

### Table 1. Typical sound insulation requirements for different building sectors.

<table>
<thead>
<tr>
<th>Sector</th>
<th>Walls</th>
<th>Floors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Airborne sound</td>
<td>Airborne sound</td>
</tr>
<tr>
<td>Residential</td>
<td>$R_w \geq 62,\text{dB}$</td>
<td>$R_w \geq 57,\text{dB}$</td>
</tr>
<tr>
<td>Schools</td>
<td>$R_w \geq 60,\text{dB}$</td>
<td>$R_w \geq 60,\text{dB}$</td>
</tr>
<tr>
<td>Hospitals</td>
<td>$R_w \geq 57,\text{dB}$</td>
<td>$R_w \geq 57,\text{dB}$</td>
</tr>
<tr>
<td>Offices</td>
<td>$R_w \geq 50,\text{dB}$</td>
<td>$R_w \geq 50,\text{dB}$</td>
</tr>
<tr>
<td>Cinemas</td>
<td>$R_w \geq 74,\text{dB}$</td>
<td></td>
</tr>
</tbody>
</table>

Compliance with acoustic regulations is generally either by pre-completion testing, carried out on-site, or via the use of standard construction details which have been proven to meet the required acoustic performance via rigorous testing.

### Walls

Walls in steel-framed buildings will generally be formed from light steel wall studs, insulation and boarding, e.g. plasterboard. Walls can be designed as load bearing or non-load bearing.
ensuring that the junctions do not provide a weak point for sound transmission must not be overlooked.

Good site practice is important to ensure that details are correctly constructed as specified, and that the primary steel frame is isolated from direct sound transfer.

Again the steel sector has developed a range of construction details to minimize flanking transmission. The example below is for the junction between a light steel separating wall and a composite separating floor.

![Construction detail for a light steel separating wall with a composite separating floor](image)

**Figure 4.** Construction detail for a light steel separating wall with a composite separating floor

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### Further information

A number of different approaches to analyzing the vibration response of buildings is available, ranging from relatively simple approaches, which may yield conservative designs, to more complex computer modeling approaches, which are more accurate but may require specialist input and advice.


On-line Floor response calculator available at [http://bcsatools.steel-sci.org/FloorResponse](http://bcsatools.steel-sci.org/FloorResponse)


Design guide for floor vibrations, ArcelorMittal Commercial Sections.

Acoustic performance requirements will vary by building type, location and the regulations in force in the relevant country or region. As such, local advice should be sought.

Good generic information and guidance on acoustics within steel buildings is available at [www.steelconstruction.info/Acoustics](http://www.steelconstruction.info/Acoustics) this includes guidance on design principles for walls, floors and junctions.


SCI Acoustic performance prediction tool for separating floors and walls available at [http://bcsatools.steel-sci.org/Acoustics/Floors.aspx](http://bcsatools.steel-sci.org/Acoustics/Floors.aspx)

### Notes to editors

Globally, construction is the most important sector for steel industry consuming, by weight, around 50% of global output.

The range of steel construction products is vast and includes:

- Hot-rolled sections and steel plate are used in building structures
- Galvanized steel coil is used for steel studs, cladding and floor decking, etc.
- Rebar used to provide tensile strength in reinforced concrete.

In some markets, the use of structural steel is commonplace but in others it is seen as a new and relatively unproven technology. Often designers and decision-makers are not convinced about the suitability of steel structures in their market due to their limited knowledge of the material’s performance, the wealth of experience and guidance available on steel construction and the wider benefits that steel construction brings. This series of factsheets aims to change this by providing facts (and dispelling myths) about the properties and benefits of structural steel.

This factsheet is one of a series of five focusing on multi-storey buildings.