5.Influence the brief

A weight off your mind: floor loadings and the climate emergency

Will Hawkins, Angus Peters and Tim Mander argue for designers to challenge overspecification and grasp the opportunity that reduced floor loads offer for low-carbon structural design.

To align with climate targets, we must reduce the embodied carbon of building structures by 10% each year[1]. Using lower design loads might be considered low-hanging fruit for reducing material consumption; a simple change which affects all structural building components, requires no alterations to design methods, no new construction technology and minimal coordination with other members of the design team. This article explores the real imposed loads in buildings, how these compare with various design codes around the world, and examines the potential savings in embodied carbon.

↑FIGURE 1: Average load used in office design, 3.1kN/m², represented as a crowd with over four people per square metre[4]

Measured loading in buildings

We know that the imposed loadings used for design are vastly greater than those reached in real buildings. MEICON collated data from eight published studies[2] where the real loading in offices was measured manually, covering a total floor area of 2 500 000m². Based on an area-weighted calculation, the mean load was found to be 0.60kN/m², with a standard deviation of 0.34kN/m², and 99.97% of the measured floor area had a load below 2.5kN/m². These studies also highlight a tendency for higher variability over smaller sampling areas.

According to the MEICON survey[3], the average office loading assumed by practising engineers in design is 3.1kN/m². This is equivalent to more than four people per square metre **(Figure 1)**. While this crowd density is physically possible, it is an extreme scenario, particularly in the context of serviceability design.

Structural failures are almost never caused by an underestimate of imposed loads, but arise due to poor maintenance, construction error, design oversight or extreme scenarios such as blasts, impacts or earthquakes[5]. In rare cases, overdesign may inadvertently act as a buffer against these failures, but the vast majority of structures remain severely underutilised.

Design codes

Most engineers are understandably wary of adopting loads below normal practice, seeing this as an unnecessary risk. However, taking the minimum codified load as a default is one of the simplest means of avoiding unnecessary material consumption, and creates a negligible risk of failure. Although building regulations in the UK require consistency with specific codes and standards, in some cases it may be possible to reduce loads further. Indeed, there is considerable variation in minimum loading values given across the world **(Table 1)** and no evidence to suggest that countries with lower requirements experience more structural failures as a result, further justifying the use of minimum values wherever possible.

Design codes recognise the reduced likelihood of large loads across larger floor areas, capturing this through live load reduction factors. However, the approach to this varies between codes. In Japan, a significantly different load is used to design primary and secondary beams, for example **(Table 1)**. The UK National Annex (NA) to Eurocode 1 features a linear live load reduction up to a maximum of 25% at floor areas above 250m². This is markedly more conservative than the basic Eurocode, which would reduce an office loading by 46% over the same area, with an absolute limit of 50%. A similar limit of 50% is given by ASCE 7-16, but this is reached at only 167m².

The UK NA is less conservative when considering storeys rather than area, with a maximum reduction of 50% applied for elements supporting over 10 storeys, compared with limits of 30% and 40% given by Eurocode 1 (offices) and ASCE 7-16 respectively.

Such reductions recognise the low likelihood of full occupancy on all floors. However, even the fully reduced minimum UK office load of 1.25kN/m², with 0.60kN/m² of this apportioned to furniture, is equivalent to a crowd of 1.2m² per person over an entire high-rise building. This is far lower than minimum feasible values for ventilation (10m² per person[6]) or fire regulations (4m² per person[7]).

While we may question their current conservatism, this analysis confirms that any live load reduction on offer should always be taken into account. In future code revisions, enhancing live load reductions may be the simplest, safest and most rational means of avoiding unrealistic overspecification. New digital capabilities for monitoring, storage and analysis of large quantities of loading data could provide the evidence base needed to justify this[8].

Carbon reduction potential

It is clear that lower loads will lead to smaller structures, but less obvious how significant the potential embodied carbon savings might be, or how these compare with alternative strategies.

Figure 2 shows the variation in upfront embodied carbon (modules A1–A5, following IStructE guidance[9]) for a hypothetical four-storey building with reinforced concrete flat slabs and a raft foundation. Elements are designed to Eurocode 2 and optimised for minimum embodied carbon using the generative design software PANDA[10]. The base-case design has a 3.0kN/m² live load and 9m spans, and emissions are plotted for variations in each.

The results show a linear relationship between imposed loading and embodied carbon, with each reduction by 1.0kN/m² saving 12.6kgCO_2e/m² (4% reduction over the base case). The majority of this saving is shared between the floor structure (6.2kgCO_2e/m²) and foundations (5.5kgCO_2e/m²).

TABLE 1: Comparison of minimum recommended floor loads for office buildings across several design codes

Country	Code	Office load [kN/m²]
UK	UK NA to BS EN 1991-1-1:2002	2.5 (superstructure) 3.0 (ground and below)
Germany	DIN EN 1991-1-1/NA:2010-12	2.0
China	GB 50009-2012	2.0
USA	ASCE 7-10	2.4
Japan	AIJ Recommendations for Loads on Buildings (2015)	2.9 (local, e.g. slabs, secondary beams) 1.8 (intermediate, e.g. primary beams, columns) 0.8 (global, in combination with wind or seismic)

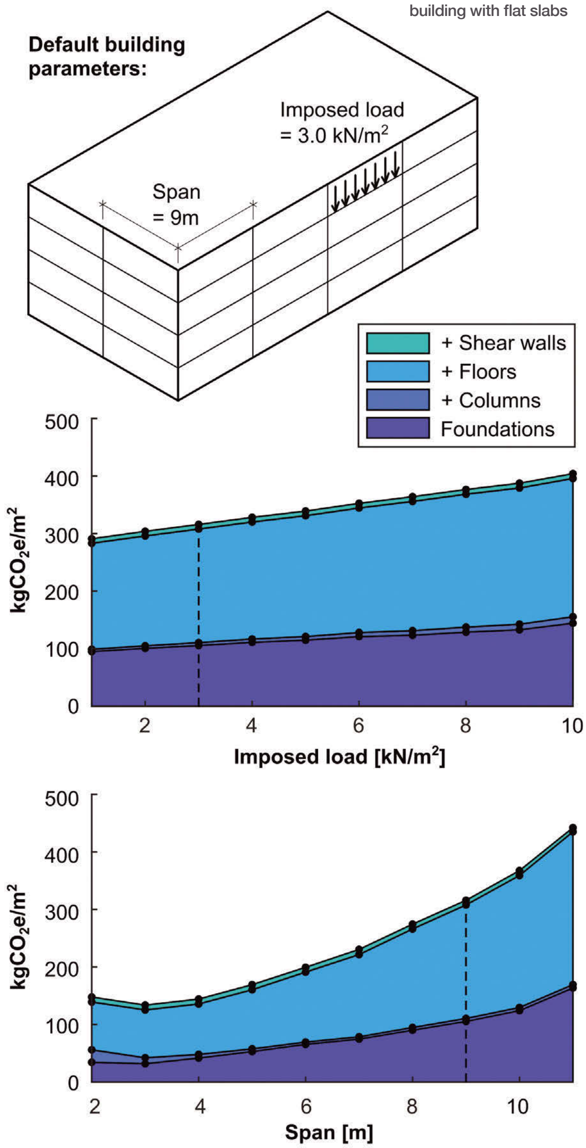

FIGURE 2: Variation of embodied carbon with imposed loading and span for four-storey reinforced concrete building with flat slabs

> “REDUCING FLOOR LOADINGS IS A COMPARATIVELY ‘EASY WIN’ WHICH REQUIRES NO CHANGE TO THE OVERALL LAYOUT

Note that the potential carbon reduction through reducing spans is much greater than through reducing loading; going from 9m to 8m saves 41.7kgCO_2e/m² (13.1%), primarily due to a reduction in slab thickness. Previous studies demonstrate additional savings through changes in material specification, floor system and foundation type[11].

While less effective than other approaches, reducing floor loadings is a comparatively ‘easy win’ which requires no change to the overall layout of the building or its construction method. A 4% saving might seem modest, but it can make an important contribution to one year’s 10% reduction target[1].

Furthermore, if all of the 5.3bn square metres of buildings constructed annually[12] reduced their imposed loading by 1.0kN/m², and achieved the 12.6kgCO_2e/m² reduction in embodied carbon found in this study, the total saving would be 67MtCO_2, which is greater than the total annual electricity consumption of the UK[13].

Enhancing opportunities for reuse and retrofit

Moving away from new structures towards increased reuse and retrofit is one of the most effective ways structural engineers can reduce carbon emissions[14]. In this context, the benefits of lighter loads become potentially highly significant, by maximising opportunities for vertical extension and foundation reuse.

Most foundations rely on large volumes of concrete, a material which will remain carbon-intensive to produce for the foreseeable future[15]. This represents a difficult obstacle on the pathway to low- or zero-carbon structures, which might be overcome through reuse of existing foundations. Balancing new loads with those originally used for design is a simple and low-risk means of verifying capacity when reusing structures[16], and reduced floor loadings directly benefit this.

Conclusion

Research shows that actual loads in buildings are consistently and significantly lower than those used in design. We also know that the minimum live loadings, and opportunities for reduction over large areas, are highly variable across global design codes. As a result, choosing loads above the minimum codified values is rarely justifiable, particularly since this has a direct impact on embodied carbon.

> “WHILE REDUCING DESIGN LOADINGS MAY NOT BE THE MOST EFFECTIVE MEANS OF DRIVING DOWN EMBODIED CARBON IN NEW BUILDINGS, IT IS STILL ONE OF THE QUICKEST AND SIMPLEST CHANGES WE CAN MAKE AS AN INDUSTRY

While reducing design loadings may not be the most effective means of driving down embodied carbon in new buildings, it is still one of the quickest and simplest changes we can make as an industry. It also shows intent, leadership and a change in mindset.

Furthermore, by normalising lower design loads, we maximise opportunities to reuse existing structures and capitalise on historic overdesign. As a result, continuing to challenge overspecification remains an important part of the transition to low-carbon structural design.

HAVE YOUR SAY

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