Framing Systems and Thermal Mass

BY MARK GORGOLEWSKI, PH.D.

New studies indicate that most framing systems—both steel and concrete—have about the same effect on a building's energy consumption.

BUILDING DESIGNERS ARE BECOMING INCREASINGLY INTERESTED IN USING THERMAL MASS TO REDUCE HEATING AND COOLING LOADS IN BUILDINGS. Doing so can lead to significant benefits in both energy efficiency and comfort.

Leaving heavyweight material surfaces exposed allows the structural mass to interact thermally with the internal environment, thereby increasing the thermal inertia of the occupied spaces. These components act as a heat sink during the day by absorbing excess heat, thus avoiding or reducing overheating. This can reduce or eliminate the summer mechanical cooling load in many building types and is particularly useful in offices that tend to have high thermal gains from occupants, IT, lighting, and solar gains through glazed façades. Winter heating loads can also potentially be reduced.

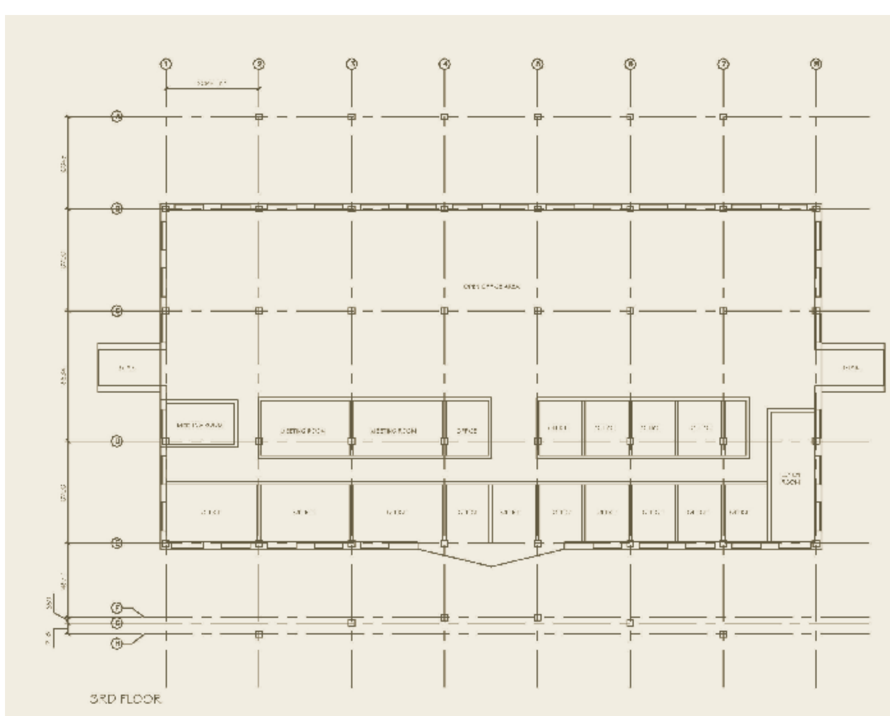
Ryerson University in Toronto, Canada, using sophisticated thermal simulation software, is currently conducting research on the importance of thermal mass in the building fabric. In most framed buildings, the floor/ceiling slabs have the largest area of useful thermal mass of all internal surfaces, especially in multi-story buildings, although mass in the external wall can also be significant. Thus, Ryerson carried out a comparison of two types of structural system used in a typical five-story office building (see figure at right).

The study compared the modeled energy use of a steel-framed office building with a typical composite steel and concrete floor slab, to the same building using a cast-in-place concrete structure. Other features, such as building form and orientation, building envelope R-values, and the HVAC system, were kept the same for both buildings. The table on the following page shows the predicted energy use for various locations in Canada, and for two ratios of glazing area to wall area.

The results indicate that the difference between the two structural materials is small—and beyond the accuracy of the modeling software. In any one location, the two buildings perform almost identically, which suggests that the steel-framed office building has sufficient thermal mass to generate the same benefits in energy use as the concrete building. Furthermore, it is clear that the glazing-to-wall ratio is a far more significant factor affecting predicted energy use.

The next stage of the study varied the specifications for the building fabric, glazing-to-wall ratio, and HVAC system controls to identify key features that affect performance. These results begin to provide some guidance for designers about the key issues involved with utilizing thermal mass. The main conclusion from these simulations is that thermal mass located in the building envelope can have some impact on the energy efficiency and thermal comfort of the building. However, this impact is complex and not always beneficial. It also makes a lesser impact than that of other key factors such as HVAC system and controls, R-values, and glazing ratio. The impact of thermal mass in the envelope may be positive or negative depending on many factors, including the overall R-value of the external walls, the ratio of window-to-façade, the solar radiation intensity at the location, the use of the building, and the control of HVAC systems.

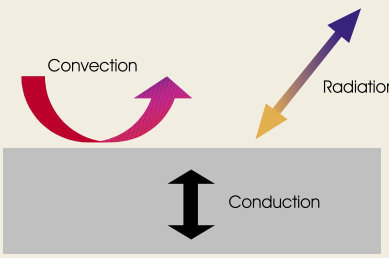
The initial modeling suggests that there exists a critical R-value of the exter-



Second-floor plan of building modeled in Ryerson University's study.

Thermal Mass in Office Buildings

Thermal mass is the ability of a material to absorb, store, and release heat. It is measured in the number of Joules of thermal energy stored per unit of mass (J/kgK), or per cubic foot of material (J/m^3K). The basic principle of using heavy structural elements, such as masonry walls, as sinks to absorb heat during the occupied period of the day is an age-old strategy for vernacular green designs.



The mechanism of heat transfer into a thermal mass, such as a floor slab.

The conditions and servicing strategies for modern office buildings are very different than these vernacular buildings. A typical office has a deep plan, high internal heat gains, large areas of glazing (leading to high solar gains), a sealed façade, a dense occupation, and internal finishes that insulate the mass from the internal space. Such buildings require a very different strategy for environmental control and the use of thermal mass.

In multi-story office buildings the floor and ceiling slabs typically have the largest area of useful thermal mass. External walls and internal partitions are often lightweight and have little useful thermal mass. Exposing the surfaces of floor slabs allows the structural mass to interact thermally with the internal environment, thereby increasing the thermal inertia of the occupied spaces. These components act as heat sinks during the day, absorbing excess heat and thus avoiding or reducing overheating. At night, the cooler ambient air is used to ventilate the internal spaces and cool the slabs, removing the heat stored during the previous day and preparing the slabs for absorbing further thermal energy the following day. This can reduce or eliminate the summer mechanical cooling load in many buildings and is particularly useful in offices that tend to have high thermal gains from occupants, IT and other equipment, lighting, and solar gains due to glazed facades.

The ability of a building element to absorb and store heat is dependent on two key factors:

- The thermal characteristics of the element itself, particularly its capacity to conduct and store thermal energy
- The rate of heat transfer between the element and the air/space to which it is exposed.

Detailed computer thermal modelling, used to analyze the performance of alternative constructions, suggests that for most construction types used in office projects, it is the surface heat transfer characteristics that determine or limit the thermal storage performance of a typical concrete floor slab—not the depth of the slab. There is little benefit from increasing the slab thickness above 100 mm (4 in.), as it is the rate at which heat can be absorbed into the fabric that is the limiting factor for how much thermal energy can be stored. For typical concrete floor construction types used in both steel and concrete frame office buildings, the capacity of the slab to store the thermal energy is superior to the rate of surface heat transfer over a 24-hour cycle.

Improvements in surface heat transfer can be achieved by increasing the surface area through the formation of coffers or troughs, or profiling the surface as is done for composite deck floor slabs. Typically, this can approximately double the exposed underside surface area and, hence, heat transfer, and is likely to be more relevant than increasing the amount of mass.

Increased surface area of a profiled composite slab, right, compared to that of a flat slab, lab.

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Predicted Energy-Use Comparison for an Office Building
Using a Steel Structure vs. Using a Concrete Structure

LOCATION	CONSTRUCTION	ANNUAL ENERGY USE ($GJ/M^2/Y$)	
		GLASS/WALL = 0.25	GLASS/WALL = 0.55
Toronto	Steel	1.23	2.07
	Concrete	1.26	2.12
Vancouver	Steel	0.97	1.59
	Concrete	1.01	1.64
Montreal	Steel	1.42	2.43
	Concrete	1.48	2.49
Calgary	Steel	1.55	2.63
	Concrete	1.62	2.72

nal walls—defined as the "Threshold R-value"—above which additional thermal mass is beneficial, and below which thermal mass leads to additional energy use and poor thermal comfort. The Threshold R-value is also dependent on the glazing-to-wall ratio and the climate. This link between thermal mass, R-value, and glazing ratio needs to be further explored and clearly understood in order to ensure that thermal mass benefits are fully exploited.

Thus, the study suggests that low-energy design requires addressing many complex and interacting factors in a comprehensive way, as a focus on only thermal mass may lead to less than optimal solutions. A future aim of the study is to propose values for the Threshold R-value for various locations in Canada and for alternative glazing-to-wall ratios. MSC

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