ADVANTAGE STEEL

CISC

Special Issue: Sustainability and Steel

GHG Emission Reduction

LEED™ with Steel through Integration

Recovery Strategies to Bypass the Grave

Thermal Mass in Buildings

PUBLICATION OF THE CANADIAN INSTITUTE OF STEEL CONSTRUCTION NUMBER 20 SUMMER 2004

From the editor

Green building design is affecting not only the construction products selected but also the processes of collaboration and integration of different disciplines. The people of the steel industry care about the environmental performance of their products and want to make a difference. As with other construction professionals, we are learning and we are gaining experience. In this issue, we want to share knowledge and information about some myths and realities concerning the important topic of thermal mass of buildings, about recovery strategies that architects and engineers can apply to increase the content of reused steel in their next projects, and about the less obvious contributions of steel in the LEED™ context through an integrated design view.
As partners of the green building process, we aim to contribute our part to develop a more sustainable environment for future generations.

Michael I. Gilmor
President
CISC

Cover: "Scrap Metal XII" Oil painting by Anna Held Audette www.annaheldaudette.com - As the artist puts it so convincingly: "In our rapidly changing world, the triumphs of technology are just a moment away from obsolescence. Yet these remains of collapsed power have a strength, grace and sadness that is both eloquent and impenetrable. Transfigured by time and light, which render the ordinary extraordinary, they form a visual requiem for the industrial age". Fortunately, the objects portrayed on this painting are truly a cradle, awaiting a new life, hence avoiding obsolescence. The environment really is everybody's business.

In this issue

Photo right: Children walking in Western Canada, where much of the green movement started.

Advantage Steel Number 20 Summer 2004

Advantage Steel and the French language edition Avantage Acier (available on request) are published by the Canadian Institute of Steel Construction (CISC) on behalf of its members. CISC is not responsible for the statements made nor for the opinions expressed in this publication by those contributing articles. CISC gratefully acknowledges the support contributed to this publication by the CWB Group. Visit us at: *www.cisc-icca.ca*
Tel: 416-491-4552, Fax: 416-491-6461

Chairman, CISC: Garry Kerrison
X.L. Ironworks Ltd.
Editor: Michael I. Gilmor, P.Eng.
Assistant to the Editor: Samantha Sampson
Technical Advisor: Charles Albert, P.Eng
Editing/Technical Advisor: Sylvie Boulanger, P.Eng. Ph.D

Please direct advertising queries to:
Publisher: Richard Soren
Design Print Media
Tel: 416-482-9339 E-mail: designprint@sympatico.ca
Design & Formatting: Tibbles, Bird & Company
Tel: 416-422-0022 E-mail: studio@tibblesbird.com

Professional engineers, architects, structural steel fabricators and others interested in steel construction are invited to enquire about CISC membership. Readers are encouraged to submit their interesting steel construction projects for consideration for inclusion in this publication by contacting CISC.

ISSN 1192-5248 PUBLICATIONS NUMBER 40693557

Please return undelivered copies to:
Canadian Institute of Steel Construction
201 Consumers Road, Suite 300
Willowdale, Ontario, Canada M2J 4G8

Sylvie Boulanger, P.Eng. Ph.D sboulanger@cisc-icca.ca

ASK DR. SYLVIE

Photo by: Adrien Voutaz

Copper and The Quality of Recycled Steel

I was reading a book by William McDonough and Michael Braungart called Cradle to Cradle, in which they make claims about steel recycling leading to downgrading of the quality of steel. In particular they talk about steel used in the auto industry and that it cannot be recycled into high quality steel suitable for cars again. What is the extent of copper use in recycling, and how does it affect the steel used in the construction sector? – M.G.

What a great set of questions. This book has become a classic, and was recommended to me by several architects. My understanding of today's steel making technology is that there is no deterioration in the quality of steel construction products made of recycled content, and that steel processes of the last couple of decades provide a reliable recycled product that is truly recyclable. But don't take my word for it, read the answer provided by Gregory L. Crawford, from the Steel Recycling Institute. He can be reached at gcrawford@steel.org.

"I've read the book in question. The comment concerning copper contamination in auto shred does appear in it. Historically, there may have been truth in that claim. That is, several decades ago, with the advent of auto shredders, there may have been an undesirable amount of copper appearing in some auto shreds. Perhaps that is the information that was reported to the authors.

However, since then, the auto dismantling industry has done a far better job of pulling "core" items from the hulk before shredding, including alternators, generators, and other such sources of copper, in order to sell this material for better profit. In fact, they are obliged to remove gas tanks, lead batteries, and so on, before being accepted for shredding. Auto shredder operators do not let their auto shred product go "out of spec" for their smelter customer.

Also, the auto industry has minimized copper use in today's cars by downsizing gauges in wiring harnesses to virtual filaments wherever possible, like conduit to, say, dome lights. We also see the use of fibre optics technology in place of a copper wire with a bulb on the end. In short, copper contamination from auto shred is not a problem in modern steel making.

It seemed to me that the authors were not so much criticizing steel but trying to make a recurring point in this book, namely, "waste is food", either for natural processes or for industrial processes. My interpretation is that steel was complimented for recycling but then admonished for supposedly letting this (no-longer-existent) contamination potentially degrade future products, being less than satisfactory "food". As I recall, the authors see complete disassembly as one of the "cures" although that approach may not be wholly practical; in some cases, it may even consume more resources in the process. Cradle to Cradle is an interesting book. I have had the opportunity to meet William McDonough. The next time I see him, perhaps we can discuss this point."

Gregory L. Crawford,
Vice President, Operations
Steel Recycling Institute
www.recycle-steel.org

Recycling is one of two steel recovery strategies. The other, reuse, of parts of a building or an entire building, also reduces waste, and is a growing trend in the industry. Both recycling and reuse are needed to maximize resources and to avoid the worst fate for a material – no recovery, i.e. the "grave", as non-biodegradable waste or an environmentally unfriendly disposal.

Getting Started on LEED™

I am an engineer and I would like to follow short courses to get a better understanding of what LEED™ is all about. Who gives these courses? Are they just for architects? Is there a Canadian version of this US standard? What exactly is LEED™? – S.C.-M. & M.D.

The best resource for courses is the Canadian Green Building Council (CaGBC). They are not just for architects although they are the ones that have been most involved initially. The CaGBC offers workshops aimed at architects, engineers, general contractors, owners and all other professionals involved in construction. A series of these workshops was first offered last winter and also at the Royal Architectural Institute of Canada (RAIC) conference. A new series across Canada will take place this fall. Visit their web site for details: www.cagbc.ca/news_events/courses

LEED™ stands for Leadership in Energy and Environmental Design. The LEED™ Green Building Rating System is a comprehensive, voluntary design and assessment tool that helps architecture, engineering and construction professionals improve building efficiency and measure the sustainability of their projects. It is a rating system that allows a final categorization of the building as uncertified, certified, silver, gold or platinum, according to the number of points compiled for its environmental performance. The US Green Building Council (USGBC) initially launched the initiative. The Council is a coalition of leaders from across the building industry working to promote buildings that are environmentally responsible, profitable and healthy places to live and work. At the moment, LEED™ version 2.1 is the reference. However, a LEED Canada version is expected by year-end. Version 2.1 is a 75-page document that can be downloaded from the USGBC web site. Visit www.usgbc.org/LEED/publications.

If you want to know more about LEED™ before reading 75 pages, I like the article by Terri Meyer Boake and Caroline Prochazka entitled 'LEED™: A Primer', in the January 2004 issue of Canadian Architect. It's an overview of sustainable design issues in the LEED™ context. It's available in the web archives of Canadian Architect online at www.canadianarchitect.com/issues/past_issues. Click on the January 2004 archive to get the article.

Other sources for architects and engineers regarding recycled content of steel, LEED™, case studies, innovations and associations, are available from our special "green steel" page at www.cisc-icca.ca/green.

Sorting Out the Recycled Content Value

A steel service centre faxed me a letter from a North American steel mill that produces W-shapes. The mill claims that for the purposes of obtaining LEED™ v2.1 MR credits 4.1 and 4.2, a value ranging from 82 to 89% can be used. How did they get these values? – J.McC.

The letter states that the steel products are made from 75-84% post-consumer and 10-15% post-industrial products. Now let's work through the lower and upper bounds that account for 90% (75% + 15%) to 94% (84% + 10%) recycled content, and apply the LEED™ v2.1 formula for obtaining the recycled content value for MR credits 4.1 and 4.2 (LEED™ recycled content = %post-consumer + 1/2 x % post-industrial content). One gets respectively 75% + 1/2 x 15% = 82.5%, and 84% + 1/2 x 10% = 89%.

So the range of 82 – 89% provided in the letter seems correct. You will find that most mills also include a value for "home scrap" which generally accounts for a few percent and includes both pre-consumer and post-industrial scrap, and occasionally some raw or virgin material. For this mill, "home scrap" represents 2-4%, and the rest is 4-6%. If you would like to refine your calculations, the Steel Recycling Institute claims that about 80% of "home scrap" can be considered post-industrial.

In a letter by another North American W-shape producer, a greater than 90% recycled content is indicated, of which 75-80% is from post-consumer sources, with the balance coming from post-industrial sources. After a few quick calculations, this provides a LEED™ recycled content of at least 79-81%. For a third mill, the values are conservatively 81-86%. Together, these three mills produce most of the W-shapes made in North America.

Having said all that, the Steel Recycling Institute (SRI) recommends using macro annual recycled content statistics for the steel industry from the SRI web site for calculating these values. You will find a fact sheet that has been very satisfactory for direct use in LEED™ by architects and engineers for more than three years, as well as other useful information. www.recycle-steel.org/leed

Ask Dr. Sylvie is a column for Advantage Steel aimed at readers seeking technical information on steel structures. Questions are welcome on all aspects of design and construction of steel buildings and bridges. Suggested solutions may not necessarily apply to a particular structure or application, and are not intended to replace the expertise of a professional engineer, architect or other licensed professional. Questions for Dr. Sylvie, or comments on previous questions, may be submitted by e-mail to sboulanger@cisc-icca.ca.

Left: Waiward Steel Fabricators Office – Edmonton, Alberta

Right: Dofasco's #3 Coke plant and coal handling system represents an area of improvement as solid and gas emissions have been reduced from the process

GHG EMISSION REDUCTION

"MAKING A DIFFERENCE"

Commitments and partnerships

Many readers are already well aware of the efforts made by mills to improve the environmental performance of their steel manufacturing processes (see Green Steel Resources right). In fact, since 1990, the Canadian Steel Producers Association's goal has been to improve energy performance by an average of 1% per year.

Since 1990, producers have improved their energy efficiency by 25%, resulting in a drop in CO_2 emissions of 20%. CO_2, or carbon dioxide, is the most important greenhouse gas (GHG). One of CISC's Mill Members, Dofasco has surpassed the average, showing a reduction in CO_2 emissions of 23% for the same time period.

In 1997, Dofasco became the first company in Canada to enter into a voluntary Environmental Management Agreement (EMA) with the federal and provincial governments. Dofasco has already met the majority of the agreement's specific commitments and remains on, or ahead of, schedule to meet the remaining commitments before the agreement expires in 2005. For more information, visit www.dofasco.ca, and click on the Environment and Energy section.

However, what readers might not be aware of, are the various approaches used by many steel specialty contractors. Have you visited one of our Members' fabrication installations lately? Modernized facilities, numerically controlled operations, ergonomic welding stations, paint recovery systems, and scrap recycling bins, all make a difference.

Recently, one of CISC's Members took the environmental approach one step further. On February 12th, 2003, Waiward Steel Fabricators, Lockerbie & Hole, and The University of Alberta signed the first Project Charter aimed at Green House Gas Emission Reduction in the construction industry. Working with a model and consultants, provided by industry leaders Suncor and Shell and the Canadian Industry Program for Energy Conservation (CIPEC), the organizations have partnered with the University of Alberta to undertake a comprehensive project aimed at Voluntary Compliance Reporting, greenhouse gas reduction strategies and supply chain management as part of their overall environmental plans.

They have invested one million dollars in what is referred to as a COGEN facility. Through cogeneration, Waiward Steel will generate electrical and thermal power simultaneously by utilizing the waste heat from a gas turbine to generate steam. This "excess" energy can then be redirected to the fabrication facility. The surplus can be sold back to the grid. Although this technology is more efficient than the technology it replaces, and there are some economical advantages, the initiative shows commitment to environmental preservation. The new technology used in this plant will definitely reduce emissions.

During the process, Waiward Steel reconsidered everything, from changing oversized motors, to replacing energy inefficient light fixtures and adding insulation. As Dwayne Hunka points out, "We expect that soon, the Federal government will be asking us to submit our GHG emission numbers just as we do GST, and we'll be ready."

– SB

Waiward Steel Fabricators have incorporated a COGEN facility to reduce GHG emission

COMMITMENTS

Green Steel Resources available at www.cisc-icca.ca/green

The 2002 Progress Report on the Environment
Canada | 2002 – CSPA*
Since 1990, Canadian steel producers have reduced CO_2 emissions by 20% and reduced the amount of energy used to make a tonne of shipped steel by 25%.
www.canadiansteel.ca/newsroom/reports

CSPA Statement of Commitment and Action Regarding Environmental Protection
Canada | 06/98 – CSPA*
The goals of the Canadian steel producers are to reduce environmental impact and to provide appropriate information to the respective communities relative to progress in these areas over time.
www.canadiansteel.ca/industry/factsheets

Environmental Progress in the Steel Industry
USA | AISI *
The amount of energy required to produce a ton of steel decreased by almost 45% from 1975 to 2001 as a result of technological improvements and energy conservation measures.
scinews.steel-sci.org/articles

Achieving Sustainable Construction - Guidance for clients and their professional advisers
UK | 2003, 8 pages - Corus, SCI* and BCSA*
This document summarises the views from the surveys and then sets out how the steel construction sector is routinely able to deliver sustainable buildings that enable clients and their advisers to achieve their goals.
scinews.steel-sci.org/articles

IISI Policy Statement - The World Steel Industry and Sustainable Development
Belgium | 2002, 4 pages – IISI*
www.worldsteel.org/publications (See sustainability)

Industry as a partner for sustainable development
Belgium | 2002 – IISI*
In February 2001, UNEP (United Nations Environment Programme) in partnership with various industry associations and organizations launched a reporting initiative to gauge progress by the private sector towards sustainable development. www.worldsteel.org/publications (See sustainability)

* *CSPA*, Canadian Steel Producers Association, *AISI*, Americon Iron and Steel Institute, *SCI*, Steel Construction Institute, *BCSA*, British Constructional Steelwork Association Ltd., *IISI*, International Iron and Steel Institute

LEED™ WITH STEEL THROUGH INTEGRATION

by Sylvain Boulanger

Photo: AEDIFICA architecture + urbanism

AEDIFICA architects use steel and glass to enclose and manage a large volume

Getting more points from less obvious categories

At a time when architects and engineers are challenged to look at the environmental rating of each component in their buildings, and when most rating systems look at the performance of each component in isolation, designers need to reformulate both the questions and the evaluation methods so they can think holistically again. Good design includes notions of natural integration. These are evaluations of how each component may affect (or be affected by) the performance of another; and thinking and designing in ways that achieve more inter-related benefits, with the purpose of improving the overall green performance of a design. The most sustainable and best building performance can only be achieved through integrated design – a process suitable for steel.

The LEED™ Rating System looks at all the components of a building, allowing all inter-related benefits to be rewarded. For this reason, using steel is not only rewarded in the Materials & Resources category, but instead the rewards are indirectly cumulatively tabulated for other evaluative categories as well, such as Sustainable Sites, Energy and Atmosphere, and Innovation and Design Process. Using steel can help other building components achieve their best LEED™ Rating in their respective categories (seemingly not associated with Materials & Resources), thus improving a project's overall LEED™ Rating. The ripple green effects of steel are described for each LEED™ category.

SUSTAINABLE SITES

In applications where poor soils bring issues of compressibility and the necessity for overall building weight reduction, the use of a steel structure becomes desirable. If pile footings also become part of the building assembly, steel can be a choice material and piles can contribute to reducing Site Disturbance and control site Erosion & Sedimentation.

ENERGY AND ATMOSPHERE

The mechanical systems are reviewed and rated in this category. Structural steel can be designed to reduce the building section by accommodating longer spans with smaller member sections, thus reducing a building's load requirements (HVAC) and the size of the required mechanical systems. This contributes to the Optimized Energy Performance criteria. The Utah Olympic Oval, for example, is an innovative cable suspension system supporting a very shallow steel truss roof. Steel is a lightweight structural solution that allows for these great spans. Furthermore, stub-girder construction and castellated beams offer web openings that provide flexibility for integrating mechanical systems and can also improve the mechanical system's performance.

INNOVATION & DESIGN PROCESS

This category may best recognize notions of integration in terms of a holistic approach to the overall project design. As an example, the Indoor Environmental Quality category rewards the use of low-emitting materials – but what about rewarding buildings that do not need these materials in the first place? Exposed structural steel eliminates the need for additional interior finishing products, which in turn saves the energy that would have been required to extract, produce, install and dispose of those products.

Also, principles of durability (not yet recognized or rewarded) can be presented in this category (see Recovery Strategies to Bypass the Grave in this issue). Steel is clearly durable in its servicing state, but it is also entirely recoverable, which fulfills the long-term mandate of durability in a global sense. Using steel also maximizes the amount of materials that can be reused and recycled in the future, after the useful life of a building. Bolted connections would also enable easy future dismantling, making it more likely to reuse such members in another building, as was the case for the Roy Stibbs Elementary School. It was built out of reused steel members from an old school dismantled in British Columbia and rebuilt 1000 km south, in Coquitlam. A well-planned, and well-designed steel assembly produces favourable contexts of recovery.

This category also rewards designs that demonstrate an economy of materials. For example, the HSS structural members in the atrium of the Greater London Authority building designed by Foster and Partners serve dual functions by circulating hot water and creating a very large-scale radiator. And the Department of Education Building in Sacramento, California (awarded Gold LEED™) illustrates the benefits of steel in designing lightweight structures – the structural and foundation systems are half the weight of an equivalent concrete structure.

When it comes to innovative atriums and natural lightcontrols, steel and glass are important components of the integration process. The PNC Bank Operation in Pittsburgh (awarded Silver LEED™) is one of the largest LEED™-rated structures – where the quality of natural light within the five-storey atrium is monitored through the integration of automated sunscreens, and a high performance curtain wall and window system. At 87 Ontario Street in Montreal (see photo left), AEDIFICA architects designed an atrium enclosing the space between two wings of the first building to the south and the second building to the north - providing natural light to all interior façades, additional indoor amenities, and a volume for stack effect integrating the principles of passive solar heating mitigation.

MATERIALS & RESOURCES

There are a total of seven types of credits – five of which can be applicable to steel [Ref.1,2]

Credit 1: ***Building Reuse*** (2 possible points) – 1 point is allocated if 75% of the building structure and shell (excluding windows) is preserved (add an additional point if 100% is preserved – along with 50% of the walls, floors, and ceilings). Steel structures are advantageous, as they can easily be modified and reinforced.

Credit 2: ***Construction Waste Recycling*** (2 possible points) – 1 point is allocated if 50% of the waste is diverted (add an additional point if 75% is diverted). LEED™ recognizes two types of waste: demolition and 'by-product' of construction.

Credit 3: ***Resource Reuse*** (2 possible points) – 1 point is allocated if 5% of the total building materials consist of salvaged or refurbished components – by cost (add an additional point if 10% is recovered material).

Credit 4: ***Recycled Content*** (2 possible points) – It is important to note that LEED™ – Version 2.1 offers two options for calculating recycled content. Option 1: 1 point is allocated if 5% of the total value of materials for the project consists of post-consumer recycled content (add an additional point if 10% content). Option 2: 1 point is allocated if 10% of the total value of materials for the project consists of a 2/1 ratio of post-consumer/post-industrial recycled content (add an additional point if 20% content). It is important to point out that a steel producer using a Basic Oxygen Furnace uses approximately 25% of existing steel to make new steel – compared to a steel producer using an Electric Arc Furnace, where about 90% of existing steel is used. Refer to the Green Steel Resources (see right), for additional facts and examples of supporting documentation.

Credit 5: ***Local/Regional Materials*** (2 possible points) – 1 point is allocated if the place of steel fabrication (where steel is formed into its final shape) is within 500 miles of the project site (add an additional point if the raw materials for the production of that steel are extracted or harvested within 500 miles of the project site – for steel, this means the final location where the metal served its last useful purpose before becoming scrap), a quantification only possible if the producers start tracking the origins of the scrap they use and produce such information in a product documentation letter.

The greatest potential of steel as a green building material can be achieved through its integration with other building systems, and the resulting ripple effects on LEED™ categories not directly associated with steel. Long-span, lightweight solutions simply lessen the environmental burden on structures. The integration of steel to serve dual functions also shows great promise. To achieve these sustainable results, early involvement of all stakeholders from the onset of the building process is necessary to achieve a high degree of sustainability.

Sylvain Boulanger is principal of BoldWing Continuum Architects and a LEED™ accredited professional practicing in Surrey, B.C. He is a graduate from McGill University and a post-graduate from Ohio State University. He practised in New York City with Skidmore, Owings & Merrill (SOM) Architects and Eisenman Architects - working on high-profile and avant-garde projects. He also conducted research while teaching full-time in the Master's of Architecture Program at the University of Calgary.

References

1. "Structural Steel Contributions: towards obtaining a LEED™ rating". Modern Steel Construction, May 2003. www.aisc.org/sustainability
2. LEED-NC Green Building Rating System™ Version 2.1), U.S. Green Building Council, November 2002 (revised March 14, 2003). www.usgbc.org

RECYCLED CONTENT

Green steel resources available at www.cisc-icca.ca/green

To calculate the inherent recycled content of North American construction steel products, one needs to know which of the two steel making processes was used. The integrated mill produces steel with the BOF (Basic Oxygen Furnace) while the mini-mill's process is based on the EAF (Electric Arc Furnace). The BOF uses 25% recycled steel (up to 35%) and the EAF is fed 90% recycled steel (up to virtually 100%). Adding the post-consumer and half the post-industrial recycled contents will generally provide a 20-25% LEED™ value for a BOF and 75-90% for an EAF. North American W-shapes are produced using the EAF. One should recognize that both BOF and EAF processes are needed for a global sustainable environment.

Steel Recycling Institute
There is a specific section adressed to architects and engineers, for dealing with LEED™ requirements available at,
www.recycle-steel.org/leed

The fact sheet is of particular interest. It contains aggregated values of post-consumer and post-industrial recycled content of steel as a function of the process (BOF or EAF).
www.recycle-steel.org/leed/2002Inherent

Dofasco Inc
A fact sheet from Dofasco, containing relative information on post-consumer and post-industrial recycled content is available from their website. Dofasco is a major supplier of sheet products used to manufacture steel decks and cladding.
www.dofasco.ca

TXI-Chaparral Steel
A letter serving as documentation and certification for the percentage of recycled material utilized in the production of structural steel products, both in terms of post-industrial and post-consumer recycled content is available on TXI-chaparral Steel's web site. TXI-Chaparral Steel is a major supplier of structural steel shapes.
www.txi.com/downloads/recycled_content_statement

Parts of this article appeared in the January 2004 and March 2004 issues of Canadian Architect, under the titles "Sustainability and Steel I: Integration" and "Sustainability and Steel II: Recovery". They were co-authored with Sylvie Boulanger.

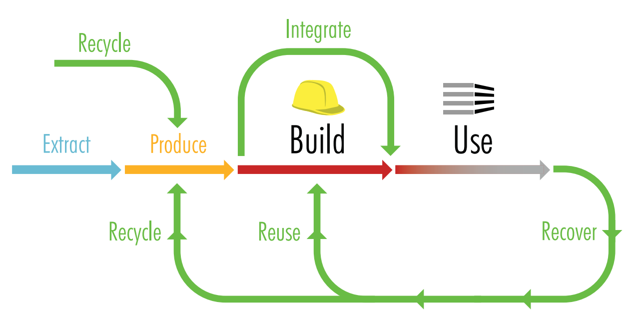
RECOVERY STRATEGIES TO BYPASS THE GRAVE

by Sylvie Boulanger and David MacKinnon

Seven questions and answers for your next project

Once ore is extracted and steel is produced for the first time, its life never ends, providing effective sustainable strategies for green building projects (Figure 1). From the onset of conceptual development steel contributes towards sustainability – most efficiently when its design is integrated with other building systems and conditions during the building process. As a building nears the end of its first-time use, steel recovery strategies can result in the reuse of elements from the original structure for another building project, the reuse of the steel structure in situ (which may include a structural design upgrade), or the dismantling and reuse of the structure at another location. Steel recovery strategies also include the recycling of steel building products (combined with other post-consumer steel products to produce other structural steel members). Recovery strategies should be considered not only at the end of a structure's life, as it is commonly done, but they should be integrated from the onset during the conceptual phase. Reuse of an existing structure or recycling of steel products extends the sustainable life of a structure and the material through multiple recovery cycles thereby honouring the “from cradle to cradle” concept and avoiding “the grave”.

Figure 1
The Multiple Life Cycle of Structural Steel



In this article, the unique nature of steel as a building material (and its infinite life) is reviewed, in terms of recovery, by answering seven questions, presenting three case studies, and concluding with comments about the future.

1. Where does one find “second-hand”steel?

“Second-hand” steel may come from a steel service centre, a fabricator's yard or more likely, from a current or future demolition site. Some steel service centres have made it their business to warehouse “second-hand” steel, which can now represent 10% of their inventory. The second-hand steel inventory consists mainly of W-shapes and angles, some tubular sections, and occasionally joists. However, one cannot expect to call a service centre, ask for 10 identical I-beams of a specific length and specific strength, and have it delivered the next day.

Although the major motivation for holding “second-hand” steel is the cost – approximately half the cost of new steel – the possibility of reuse for obtaining LEED™ points is promising, even if at this point the option appears more feasible for smaller projects. Through leads from structural engineers who track previous projects and keep close contacts with demolition companies (see Example 1), one can find and pre-select some members.

What about joists? One’s best chance is to have good contacts with demolition crews before a building is torn down, and make sure the joists are handled with care.

One suggestion is to find the used joists first, and then finalize the layout according to the available lengths instead of vice-versa – a lesson learned from the Mountain Equipment Coop project in Montreal. However, engineers from Saia Deslauriers Kadanoff were still able to integrate reused tubular sections for the fabrication of the main trusses and the climbing sculpture. They were larger than what was needed – as is almost always the case when one reuses steel – but that did not prove to be a problem. One should also consider asking what is available to the fabricators involved in your project – possibly another member of the early-integrated design process.

The main trusses of the Mountain Equipment Coop building are partly made of reused hollow structural sections

2. How can one be sure of the quality of the reused steel?

The quality of the reused steel is provided by a mill test certificate or the results from a coupon test (see Question 3). Any batch of steel produced today comes with what we call a "mill test certificate". A mill test certificate provides important information about the chemical and physical properties of the steel. If you have a mill test certificate, even a few decades old, and the steel meets today's required chemical and physical performances, testing is not needed. Hence, it would be wise to make it a practice to keep those certificates for the future. Another, yet conservative, approach is to rely on clause 5.2.2 of the steel standard CSA S16-01, which specifies that the yield capacity used to calculate the resistance of unidentified steel shall not exceed 210 MPa.

However, you will want to test the steel if you need to know either of two criteria, or both: weldability and strength. Weldability dictates whether we can attach steel elements through welding to make connections or improve capacity. Of course, bolting is always an option if welding is undesirable. By strength, we mean the yield strength, F_y, and the ultimate tensile strength, F_u, of the steel. If you are only concerned about weldability, you may decide to have just the chemical test performed. In such a case, you only need a small sample of steel. However, if physical properties are required, you will need to take one or more test samples of the steel, called "coupons" (see Question 3).

It is important to note that the recycled content of the reused steel cannot be determined through testing. Traces of certain impurities might give you hints but that is not a reliable measure. With regards to steel performance, the homogenous nature of steel allows the information coming from a coupon test to assess the capacity of the steel within the high-level of confidence of current standards.

3. How does one go about testing steel for reuse? Is it expensive?

One needs to cut out a test coupon generally 300 mm long and 50 to 75 mm wide, located in a neutral zone. A neutral zone is an area where the stresses are not too high, and preferably not too visible. However, the decision to take one, four or twelve coupons on existing steel members is usually based on the structural engineer's confidence in the material, and the apparent diversity of sources.

One basic test will generally cost less than $500 if the coupon is delivered to the testing company, and up to $1000 if the testing company is asked to take the coupon on site. A typical palette includes a chemical test, and a mechanical test. The chemical test indicates the carbon, iron and silicon content, which will result in an "equivalent carbon" content, to evaluate the weldability of the steel. The usual mechanical test is a tension test to determine the stress-strain characteristics, e.g., yield strength, ultimate tensile strength and elongation (see Clause 5.2.3 of CSA S16-01 and CISC Commentary for more detailed information).

4. When can one consider reusing a steel structure "in situ"?

It depends on the condition of the original steel, the age of the structure, the information you have from archived drawings, and whether you need to reuse it "as is", retrofit it to satisfy current seismic criteria, or reinforce it through welding. Data about where and when the steel was produced, and to what standard, all help the engineer assess the structure. A recent example of a complete stripping of a steel building frame and the transformation into a new use is the BMW showcase building in Toronto.

It is interesting to note that historically, the steel industry made technological leaps as early as the turn of the 20^{th} century. Hence, as far back as the 1910s, steel was already a relatively homogeneous and reliable material, and for that reason, steel of that vintage can still be reused today (see Example 1).

On the other hand, concrete became an improved building material only after the 1950s, and that is one of the reasons why there are fewer concrete buildings or bridges before that period that can be reused or refurbished without major rework.

The testing company X-per-X says that steel coupons from older structures are regularly tested, and are rarely assessed as unusable. The most concern engineers have with steel produced prior to the 1950s is its weldability, which is a function of the higher carbon content present in many of the grades produced during those years. Even then, higher carbon steels can be welded successfully with slight modifications to standard welding procedures.

Incidentally, X-per-X and engineers such as Pasquin, St-Jean et Associés (see Example 2) find that engineers of that era tended to design "adult" size columns and beams, that is, heavier sections were employed creating a reserve capacity compared to the newer lighter designs. In addition, the occupancy loads for which the original structure was designed may have been much higher than those of the new occupancy.

Unbolting ROM composite girders

Photos courtesy of Halsall Associates

Example 1. - Bits of the Royal Ontario Museum (ROM) become pieces of the University of Toronto Scarborough Student Centre

University of Toronto Scarborough Student Centre new home for ROM girders

(Date of reused steel: 1970s)

In 2003, Dunlop Architects were asked by University of Toronto students, who are members of the building committee, to provide a building that reflected a sustainable approach for their new Student Centre. In fact, the students did not understand why such an approach was not adopted by default for all buildings under construction today. Dunlop Architects and Halsall Engineers came up with the idea that part of the material could come from existing sources. Halsall, who was working on demolishing part of the ROM building, proposed reusing ROM girders for the new Student Centre. Since Halsall had done that part of the ROM building in the late 1970s, they had all the necessary archives for demonstrating the material quality of the steel to be reused – therefore no testing was required. A greater challenge was for the architect to find the right official from the ROM building to speak to the right University of Toronto official, for accepting the (donated) steel. This administrative aspect had to be factored into the project scheduling of this reuse. The reused steel amounted to approximately 18 tons of saved steel.

What can sometimes be more difficult with the steels of that era is obtaining the proper dimensions for calculating their capacity. Fortunately, reusing steel has been relatively common since the turn of the century and a guide published by AISC indicates sizes, yield strengths and other useful information for rehabilitation purposes. Steels produced after the 1950s generally pose few problems, except that the yield strength might be lower. Irrespective of carbon content, steels made after 1910 can always be recycled.

5. When can one recover an entire steel structure by dismantling?

Bolted structures are very conducive to being disassembled and moved. Fortunately, that is the case for most steel structures, where most of the welding takes place in the fabricator's shop and transportable pieces bolted together on site. There are several factors that will influence the process: the types of connectors, the bracing elements, the spans of beams, the complexity of the column splices, and, the use of composite construction. Basically, when planning for relocation, use mechanical fasteners and avoid composite construction. Steel erection specialists rather than demolition crews will generally be required to perform the dismantling and erection of the structure at a new location. This area is rapidly evolving and already some specific standards addressing these issues are being considered by the Canadian Standards Association. Although designing for deconstruction is not yet an established practice, it has been, and is presently being done for several structures. In the 1990s, an entire school in BC was moved 1000 km south (see Example 3); in this decade, several small industrial buildings in the Maritimes have been dismantled and relocated for a new use, and still standing today, is the Montreal Expo 67 Russian Pavillion…in Moscow!

6. How do demolition crews go about recovering steel?

It depends if the steel is to be cut into pieces for recycling or dismantled for reuse. Murray Demolition has the policy of leaving no steel behind. To extract steel members for reuse, Murray Demolition comments that there are basically two methods: unbolting or shearing. In the case of the ROM building (see Example 1), the beams to be reused were unbolted. Since the floor system was composite (i.e.: shear studs welded to the top flange of the steel beams and imbedded into the concrete slab), some supplementary cleaning was required. The 38 ft long beams from the ROM were shortened by the fabricator to 32 ft long and reused for the University of Toronto Student Centre. Shearing (using giant metal scissor-like equipment) the member near the connection or support introduces residual stresses. Hence, the member is further cut back 2 or 3 feet in the fabricator shop using more refined cutting equipment and new connection material applied. The impact of shortening the members is that most reused sections will be deeper than required, often creating reserve capacity.

Demolition crews find that the behaviour of steel buildings is more predictable than a similar concrete building whose behaviour under demolition is directly attributable to the behaviour of the exposed rebars. If you compare a 3 million s.f. steel building to a 3 million s.f. concrete building, the steel building will cost $0/s.f. to demolish compared to $2-3/s.f. for the concrete building. The reason is simple – most of the steel can be salvaged and becomes revenue, whereas there are only costs associated to the disposal of the concrete.

Connecting new beams to old columns

Photos: Stephen Poulin

Example 2. - The Eaton building in Montreal becomes Le Complexe les Ailes

(Date of reused steel: 1920s – 1950s)

In 2002, Lemay & Associés took the Eaton building in Montreal and refurbished it into the new and elegant Complexe les Ailes. Although part of the structure was gutted to create an ovoid atrium, much of the structure was reused. Most of the steel, which dates from several eras ranging from the 20s to the 50s, could be reused – as concluded by the engineering firm Pasquin St-Jean which had coupons of the steel tested for its yield strength, and carbon content. It turns out that the low yield strength of that period could be compensated by the fact that many of the members were oversized, a common practice for that period. Even the columns could be reused. Although the steel had higher carbon content than the new steel, it was still possible to weld onto it. The roof was refurbished as a floor, necessitating extra joists between the existing ones. As far as the rest of the building is concerned, a major portion of the complexity was due to problems with interfaces between different parts of the building built at different periods, and the new parts, complicated by non-typical geometries. The team explained that they would have all benefited from more extensive visual assessments and testing earlier in this fast track project.

7. How easy is it to recover steel for recycling?

Although the answer depends on the initial site, in general the skeletal and assembled nature of a steel structure facilitates the process. In an unusual situation such as the steel from the World Trade Centre twin towers, 95% of structural beams and plates were recovered, and 50% of the reinforcement bars. These ratios also correspond to the estimated recycling rates of both of these products according to the Steel Recycling Institute. When recovering cars, some shredders can reduce an automobile into small chunks in 45 seconds, or approximately 80 to 100 cars per hour! In 2001, 14.5 million cars in the US fed the open loop of recycling this way. In fact, approximately 96% of all steel from automobiles is currently recycled. Steel is collected not only from used auto parts yards, but also from demolition sites and industrial manufacturers. Companies such as SNF (Société Nationale de Ferrailles) specializing in the recovery of steel, rely on electromagnetic cranes, powerful guillotine shears and huge machinery for sorting, shredding, shearing, crushing and reducing metals to bits, pieces or fragments. Recovery of steel from demolition sites is fairly straightforward provided it is not contaminated, or that no other material is attached (see Example 1). Additional processing (energy) is

The Cassiar school becomes the Roy Stibbs School

Example 3. - Cassiar School in B.C. gets dismantled and reused 1000 km away

(Date of reused steel: 1990s)
When the mining town of Cassiar in northern B.C. was shut down in 1992, its steel-framed secondary school was abandoned after only one year of service. The school was nearly forgotten until a fire destroyed the Roy Stibbs elementary school in Coquitlam. The need for a replacement by the fall of 1994 was so urgent that it was decided to dismantle and reuse the Cassiar School, located 1000 km away. Approximately 75% of the steel frame in Cassiar was shipped piece by piece, with each member labelled according to the mark number on the shop drawings. The higher seismic requirements in Coquitlam and the different classroom layout requirements of an elementary school posed an immediate challenge, according to Bush, Bohlman & Partners. The bracing system had to be modified.
Prior to the erection at the new site, the structural steel was inspected by independent materials testing consultants, to ensure that any damage caused by dismantling or transportation was properly identified.
This unique reuse of an existing building on a new site not only contributed to a greener building, but also saved significant time and money.

needed to separate attached materials, which explains why the recovery rate for rebar is more expensive and about half the rate of that of steel beams and girders.

THE FUTURE

The future of steel recovery is very green, both in terms of reuse and recycling. In terms of reuse, more work needs to be done with respect to the sharing of information on potential reuse projects and the availability of recovered steel. At the moment, reused steel requires a one-of-a-kind individual effort. We would like to suggest that structural engineers together with demolition companies and fabricators, can greatly contribute to the development of steel service centres' warehouse database for reused steel – which would offer the design and construction industry links to available material.

Some warehouses could cater exclusively to reusable steel that has already been tested and whose dimensions are known. To evolve in this direction, the Canadian Institute of Steel Construction, Natural Resources Canada, as well as academic and industrial partners may be collaborating in the near future to get a better appreciation of material flow (Figure 1). Specifically, just how much steel gets reused? What are the obstacles encountered? How can we improve the process of reuse through better communication?

The industry catering to recycling has a strong history, which can only continue to contribute to a future of possibilities. Although information needs to be more readily available, all signs indicate that improvements will continue given the many environmental and economical advantages that recycling steel offers, particularly as it is an 'open loop' material.

As we await such developments, it makes good sense to involve structural engineers and fabricators early in the design of a green steel building, as they are more likely to have knowledge of possible demolition sites or other sites (to be inventoried and explored for possible recovery). This contributes to a more integrated design approach, better LEED™ ratings, effective recovery results and consequently better green buildings. Steel recovery strategies will no doubt help a building bypass the grave.

The authors would like to thank the following people for their comments and contribution: Sylvain Boulanger, Boldwing Continuum, François Deslauriers, Saia Deslauriers Kadanoff Leconte Brisebois Blais & Associés, Pierre Larouche, Lemay & Associés, Normand Leboeuf, Pasquin, St-Jean et Associés, Stephen Phillips, Dunlop Architects, Michael Jelicic and Shahé Sagharian, Halsall & Associates, Harry Virdee, Mirage Steel, Kareem Elkhatib, Murray Demolition, Simon Pesant, S.N.F. Société nationale de ferrailles, Ken de Souza, Dofasco, Yvan Hubert, X-per-X.

Sylvie Boulanger and David MacKinnon are CISC staff.

A different and shorter version of this article appeared in the January 2004 and March 2004 issues of Canadian Architect, under the titles "Sustainability and Steel I: Integration" and "Sustainability and Steel II: Recovery". The articles were co-authored by Sylvie Boulanger and Sylvain Boulanger.

THERMAL MASS IN BUILDINGS

by Mark Gorgolewski

Sorting the myths from the realities

An increasing desire to address the issue of man's impact on the environment is leading to a fundamental review of how we construct and operate our buildings. The impact of the LEED™ green building rating system in North America, and the adoption of the Climate Change Plan for Canada, which has set targets for improved energy use in commercial buildings, have both led to a greater interest in reducing energy use in buildings. It is increasingly recognized that the use of thermal mass in office buildings can offer significant energy efficiency and thermal comfort advantages, and this has led to more interest from architects and engineers when designing low energy, sustainable office buildings.

However, a lack of understanding of the detailed mechanisms that affect thermal mass and how it can be used in modern office buildings has led to a tendency to equate high levels of physical mass with good passive thermal performance. Designers assume that physically massive buildings are required to provide sufficient thermal mass. In reality, there are many other factors that need to be considered and increasing physical mass above certain thresholds does not necessarily improve thermal performance. Many commercial buildings today are structurally heavy but thermally lightweight. This is due to the use of finishes such as false floors, drop ceilings, gypsum wall linings, carpets, and other insulating finishes that effectively insulate the heavy structure from the internal environment. Generally, it is more important to ensure that the design makes best use of available thermal mass than to add additional mass. It is also relevant to consider the likely increases in heat ing load in the winter which may result from additional thermal mass.

Figure 1: Wessex Water headquarters achieved one of the best environmental ratings for an office building in the UK using a steel frame with precast concrete floors

Why use thermal mass

Thermal mass, (or thermal capacity) is a material's ability to absorb, store and release heat. It is measured by the number of Joules of thermal energy stored per unit of mass (J/Kg·K), or per cubic metre of material (J/m^3·K). Generally heavy materials such as concrete and masonry can store more heat per unit of volume than lightweight materials such as timber or insulation (Table 1). 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 used for vernacular designs in warm countries such as in the Mediterranean. Such buildings use high mass, variable air change rates, large surface areas, shading and low internal heat loads to control overheating. However, often there were penalties in the form of poorer comfort in winter or increased need for heating.

Table 1 Properties of common building materials

Material	Material density (kg/m^3)	Specific heat capacity (J/kg·K)	Volumetric heat capacity (kJ/m^3·K)	Thermal conductivity (W/m·K)
Steel	7800	480	3744	55
Concrete (normal)	2400	910	2184	1.83
Concrete (light)	1850	850	1573	1.0
Limestone	2350	810	1904	2.0
Common brick	1920	835	1603	0.72
Softwood	610	1420	866	0.13

The conditions and servicing strategies for modern office buildings are very different to Mediterranean 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 high density of 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. Typically, in multi-storey office buildings the floor and ceiling slabs 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, 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 which tend to have high thermal gains from occupants, IT, other equipment, lighting, and solar gains through glazed façades.

Benefits of Thermal Mass

The appropriate use of thermal mass can contribute significant benefits in both energy efficiency and comfort within buildings, including:

- Less reliance on mechanical services to achieve comfort.
- More stable daily temperatures in both summer and winter giving greater comfort to the occupants.
- Lower peak loading on the HVAC plant for both the heating and cooling systems.
- Increased potential for passive cooling in summer.
- Reduced cooling loads in air-conditioned buildings.
- The potential for reduced running costs resulting from lower energy use.
- Potentially reduced capital costs resulting from lower capacity cooling plant.
- A possible reduction in the volume of building interior taken up by building services.

But how much mass is appropriate in an office building, and how can the designer ensure that it is usefully integrated?

Heat transfer mechanisms

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 the thermal energy (thermal conductivity measured in W/m·K and thermal capacity measured in $J/m^3 \cdot K$).
- The rate of heat transfer between the element and the air/space to which it is exposed (the surface heat transfer in $W/m^2 \cdot K$), or also defined as the Admittance (i.e. the rate at which a square metre of surface can absorb heat from the air at a temperature difference of 1^oC).

Detailed computer thermal modelling carried out to analyze the performance of alternative constructions suggests that, for most construction types used in offices, it is the surface heat transfer characteristics that determine or limit the thermal storage performance of a

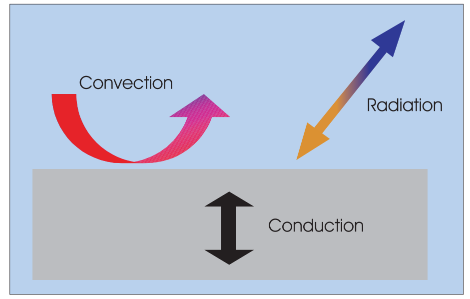


Figure 2: the mechanism of heat transfer into the thermal mass

typical concrete floor slab, not the depth or volume of the slab[1]. It has been found that there is little benefit from increasing the slab thickness above about 100 mm 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[2]. 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, troughs, or profiling the surface such as is the case 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. Current research into improving heat transfer[3] includes blowing air through cores within the floor slab, or using water in embedded pipes to warm and cool the slab.

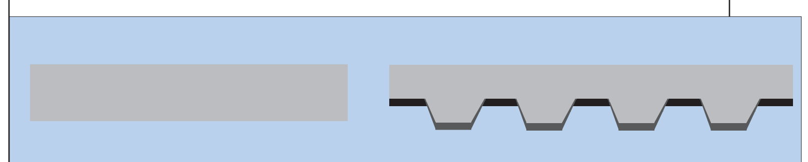


Figure 3: Increased surface area of a profiled composite slab, compared to a flat slab

People will feel comfortable at higher internal air temperatures when there are cool surfaces in a space. This is because the comfort temperature we experience within a space is dependent on both the air temperature and the radiant temperature of all the surfaces within a space. Thermally massive components tend to have cooler surfaces, which in summer provide a cooling effect through radiative cooling to people within the space (the opposite of radiator heating in the winter). This will further reduce the cooling load, but may lead to increases in heating load in winter.

Finishes

The widespread use of such features as false ceilings, carpets, floor voids, and gypsum wall liners, all of which effectively insulate the thermal mass from the internal environment, considerably reduce the effect of thermal mass in the structure. These factors are more important than the framing material of the building, and the designers need to investigate options such as ceramic floor finishes and exposed concrete ceilings to ensure that the mass is connected to the space.

The use of solid drop ceilings obviously limits heat transfer by effectively insulating the slab from the space below. However, a significant level of heat transfer may still be achievable if the ceiling itself is made of a conducting rather than insulating material. Furthermore, partial thermal exposure of a slab surface can be achieved by using open cell or perforated ceiling tiles, or covering only part of the slab with a drop ceiling. This permits air to circulate between the ceiling void and space below making direct use of convective heat transfer. Research in the UK has suggested that as little as 15% of open area could be sufficient to allow significant air circulation and heat transfer[4].

Other issues

It is important to note that there are several downsides to the exposure of thermal mass in office buildings. Computer thermal modelling suggests that in the winter months a 10 to 20% increase in heating energy demand may occur due to the additional heat required to warm the thermal mass. Thermally massive building will cool more slowly when heating is switched off in a winter evening, but will take longer to warm up in the mornings before occupation. As a result of the higher temperatures at night in the building there will be a higher rate of heat loss. This is exacerbated if the building is poorly insulated and can lead to significantly increased heating costs. Conversely, during spring and autumn, lightweight buildings may require both heating and cooling over a 24 hour cycle, whereas the thermally heavy buildings may maintain comfortable internal conditions without either supplementary heating or cooling. The balance between the reduction in cooling demand and increase in heating demand is a complex one and will vary between buildings, being dependent upon the envelope design responsiveness of controls, occupancy period and the heating system design.

Exposing the underside of a concrete floor slab to take advantage of thermal mass also has implications on the acoustic environment of the space and the integration of services including lighting. The absence of a suspended ceiling can give rise to increased reverberation times and increased reflected sound across an open plan space. This can be addressed by using acoustically absorbent partitions, although these may affect day lighting levels, or by integration of acoustically absorbing panels in light fittings suspended below the slab. Alternatively, partial drop ceilings may be appropriate.

Conclusion

To exploit thermal mass, the choice of structural system need not be limited to any one particular material or system and sufficient mass may readily be integrated into a steel frame structure. Since exposure of the mass is the most critical issue, the important aspect the designer must consider is how to ensure that the floor slabs are not insulated in such a way as to make the mass within them redundant. The design of the structure can be optimised for structural reasons and there is little benefit in adding mass purely for thermal reasons. Deeper slabs and more concrete are not necessary. Rather, it is the amount of exposure of the thermal mass to the internal spaces through increased surface area, and the types of surface finishes (such as carpets, drop ceilings, etc) that are more important to the efficiency with which the thermal mass is utilised. It may be appropriate to use different solutions depending on the location within a building. North facing spaces have less solar gains so overheating may be less of an issue than in south facing locations.

The Steel Structures Education Foundation is funding further research into the appropriate integration of thermal mass into steel frame buildings, so more information and guidance relevant to Canadian climate zones will be available next year. However, it is clear that improving thermal performance requires many factors to be considered together in an holistic way. The servicing strategy, insulation levels, air-tightness, cladding design, control of solar gain, lighting systems and finishes should all be considered in an integrated way to provide the optimal solution.

Thanks to Daniel Pearl for his comments on this article.

References

1 See Barnard, N. Making the most of thermal mass, Architects Journal, 21 October 1999
Or Cousins, F. & Lang, B. Aspects of structural and thermal mass, seminar paper available from the Steel Construction Institute, UK

2 Barnard, Nick & Ogden, Ray, The thermal capacity of steel frame buildings, Seminar Paper, July 1996, available from the Steel Construction Institute, UK.

3 See for example Kendrick, Chris, Active fabric energy storage systems for steel framed non-domestic buildings. Chartered Institute of Building Services Engineers (CIBSE) National Conference, Harrogate, October, 1999.
Or Kendrick, Chris & Ogden, Ray, Use of embedded water pipes to provide thermal comfort in steel frame buildings, Proceedings of the IISI conference, Steel in sustainable construction, Luxemburg, May 2002.

4 See Barnard, Nick et al, Modelling the performance of thermal mass, BRE Information Paper IP6/01, Building Research Establishment, UK
Or Amato, A. et al, Practical ceiling solutions for thermally efficient steel frame buildings, 1998 CIBSE National Conference

Mark Gorgolewski is an Associate Professor in the Department of Architectural Science in the Faculty of Engineering and Applied Science at Ryerson University in Toronto and a LEED™ certified professional. He received his Ph.D at Oxford Brookes University on the subject of energy efficiency in buildings and became a leading researcher and author in the UK prior to emigrating to Canada. He has authored several major publications and 14 technical bulletins on environmental issues for the Steel Construction Institute, the International Iron and Steel Institute and the Building Research Establishment in the UK. He is the past chair of the Association for Environment Conscious Building (AECB) in the UK.