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The Future of the Building Envelope: Building Upon our Past

ZERO IS A NUMBER:
Carbon Neutral Design Pushes the Science back into the Building Envelope

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The current push towards Carbon Neutral and Net Zero Energy building requires a focused shift from the broad and oft vague notion of Sustainable Building to one that values scientific accuracy and testing. With continuing issues surrounding sustainable design, and more recent concerns about Global Warming and CO_2 levels in the environment, it is becoming clear that even the highest standards of construction that are regularly being implemented today are simply not enough to achieve Net Zero Energy construction. Zero Carbon is perhaps the newest sustainable design initiative and is the subject of a massive amount of current research and development. As such, there are not any clear and simple guidelines to follow when considering designing building envelopes or buildings in general to meet this important target.

The carbon associated with buildings in developed countries is stated to account for at least 40% of world wide greenhouse gas emissions. If the transportation associated with urban sprawl is also taken into account, this number climbs much higher. The carbon associated with buildings can be subdivided into that associated with the building's operating energy, embodied material energy, transportation energy as relates to its occupants travel requirements, and carbon emissions related to the landscape (ecosystem disturbance or regeneration) and site design. *The design and detailing of the <u>building envelope</u> relates directly to carbon emissions arising from operating energy and embodied energy.* At the present time most initiatives to reduce GHG emissions are targeting operating energy over embodied energy. Operating energy is considered to represent around 80% of the carbon problem, and is simpler to both predict and reduce. Embodied energy is more complex to calculate given the inclusion of transportation and manufacturing energy components. Material choice carries with it synergistic potential to affect passive heating and cooling strategies, which further complicates value assessments.

In order to truly achieve a Net Zero "balance" between the operating energy of the building and the supplied site and regional based renewable energy, increased pressure is placed on the performance of the building envelope. Holistically, the overall design of the building must begin to look back to more vernacular based, passive design strategies to reduce the energy required for heating, cooling and lighting the building. This necessitates a climate-based response that is regional.

The strategies discussed are for a climate that is dominated by heating degree days. The starting point for low carbon design is the assessment of the heating versus cooling degree days of the site. If the heating degree day requirements greatly outweigh those for cooling degree days, priorities will be placed on envelope design to prevent heat loss and promote solar gain. Low carbon strategies that address the potential for the complete elimination of the use of fossil fuels, and the maximization of the use of renewable energy to operate the building, are also considering the expansion of the accepted “comfort zone” for the interior environment. Current practice for many building uses has a narrow range of acceptable temperatures and normally will switch directly from heating to cooling without including any time (of year) that presumes to attempt to arrive at a level of interior comfort without mechanical assistance.

Such buildings will also contemplate that there may be a stretch of days during the year where the interior environments may be less than optimal – but in consideration of the temporary nature of this situation, prefer not to adjust the design for the worst case in order to target lower overall energy consumption. For some building uses this might also suggest the complete elimination of A/C systems. Although most occupancy types have become accustomed to A/C during the cooling months, such practices were not common before envelopes become over glazed, sealed and devoid of external shading. With better envelope design, cooling loads can be drastically reduced, natural ventilation achieved, and therefore open the potential for the elimination of this system.

The potential for the elimination of the A/C system also begs an examination of the humidity levels of the local climate. Drier regions with equivalent cooling degree days, in contrast to more humid regions, will be more amenable to this design strategy.

The envelope strategies discussed in this paper will focus on envelope function as it impacts heating, cooling and daylighting.

DIFFERENTIATING SKIN LOAD VS INTERIOR LOAD DOMINATED BUILDING WALL REQUIREMENTS

Envelope strategies will need to be differentiated for *skin load dominated buildings* versus *interior load dominated buildings*. These two basic functional types present fairly polar requirements for their window to wall ratio as a direction function of their priority for control of heating, cooling and daylighting. These building types will also have different code requirements for general insulation levels, glazing ratios and access to natural ventilation in the form of operable windows.

Skin load dominated buildings cannot depend upon people and equipment to create heat and are more concerned with heat loss in a cold climate. Uses may include residential (houses, dormitories, long term care), smaller commercial and some institutional (as a function of low number of occupants and less equipment). These may also be able to eliminate the requirements for A/C systems altogether, as a function of the envelope design. Residential typologies can be more tolerant of an expanded "comfort zone", and occasional discomfort in that it does not interfere with "productivity" and also that occupants can assume more flexible occupancy patterns as a function of mild discomfort. Within skin load dominated buildings different uses will have varied daylighting requirements that will impact low carbon priorities. Residential buildings have lower needs for widespread daylighting. Most residences can provide adequate daylight for normal activities through current fenestration patterns – even if constructing to Code minimums. Smaller institutional and commercial occupancies may need better daylighting, inferring a higher window to wall ratio.

Current Code minimums for insulation and R-values for skin load dominated types (noting low-rise residential use) are well below current practice for Low Carbon buildings. Code minimums for insulation for interior load dominated buildings are even further away from the levels needed to drastically reduce operating energy.

Interior load dominated buildings, even in a cold climate location, may prioritize cooling to rid the building of excess heat generated by higher occupancies and equipment. Plug loads have begun to dominate energy use patterns for these buildings, which not only require additional power to be generated by renewable sources, also inject more waste heat into the interior environment, exacerbating cooling issues year round. These buildings normally supply heat around the perimeter to compensate for increased losses (and draughts) due to high window to wall ratios.

Office and other institutional typologies that are attempting to maximize daylighting to gain LEED™ credits and create pleasing interior work environments will often choose to use extremely high window to wall ratios. The daylighting will need to be designed to meet minimum requirements based upon tasks, but the current practice of wall to wall, floor to ceiling glazing, is in excess of the amount of glazing required to meet these levels. The expansive use of glass can easily compromise the thermal efficiency of the overall envelope, resulting in higher winter losses and if inadequately shaded, excessive summer gains. At present, few of these fully glazed types incorporate any exterior shading.

The successful application of Low Carbon strategies will also be a function of *owner occupied versus tenanted properties*. Tenanted properties may also be differentiated by those where the Tenants pay the utility bills versus those who do not. The direct impact on the operating costs and benefits to the proper implementation of the proposed practices will be more successful if the occupant is able to see the rewards for their efforts – particularly if some aspects of a revised envelope design require interaction with the occupants. This feeds into the realities of automated versus manually modified envelopes. In simple terms, does the occupant raise/lower the blinds, open/shut the windows, or is it controlled by a computer or a daily override system. The successful building envelope design must be "easy to use", or destined to fail.

The proposal for alterations in the design of the building envelope in this paper looks to modify the detailed design of the envelope as a function of the building use, additionally differentiated by interior versus skin load dominated type. The case in point would be low-rise versus high-rise residential buildings. Both residential occupancies have similar numbers of occupants and needs for heating, cooling and daylighting, yet Part 9 buildings have significantly higher insulation requirements at the present time than do high-rise condominiums, which are often quite fully glazed, and under the Code are classed as commercial buildings. As sustainable practices seek to minimize urban sprawl through densification of cities, more people will be housed in mid to high rise residential types. The number of "R-2000" 50 storey condominiums is presently very small. This infers that in order to approach low carbon status for operating energy, high rise residential buildings will have to look at envelope redesign that reflects a heating priority and the potential elimination of A/C, over a daylighting priority that has (erroneously) been assumed under the commercial designation. This will necessitate a complete re-visioning of the wall systems for high rise residential including more than a simple modification of the window to wall ratio.

TARGETING OPERATING ENERGY

The four basic steps that are required to *begin* to design a building to meet a zero carbon target for operating energy, in order of importance are:

#1 - **Reduce loads/demand first** (bioclimatic design, orientation, passive solar design, daylighting, shading, orientation, use of natural ventilation, site design and materiality.)

#2 - **Meet loads efficiently and effectively** (energy efficient/effective lighting, high-efficiency/effective mechanical, electrical and plumbing equipment, controls, etc.)

#3 - **Use on-site generation/renewables to meet energy needs** (doing the above steps *before* will result in the need for much smaller renewable energy systems, making carbon neutrality achievable.)

#4 - **Use purchased Offsets** as a *last resort* when all other means have been looked at on site.

Unlike many of the green rating systems or standards, the above criteria can be applied to *any* building or project, including commercial, institutional and any density or height of residential building. The design and detailing of the building envelope is critical to the reduction of energy loads for the building as a result of heating, cooling and lighting. *Of these four requirements only "#1 – Reduce loads and demands first", is of critical importance to establishing new low carbon requirements for the design of the building envelope.*

The envelope will need to meet high performance and energy efficient criteria as the primary means for reducing the need for non passive heating and cooling methods. This reflects back on some LEED™ criteria that might already have been considered. For cold climate design heating the first priority is placed on resisting heat loss. This practically means increasing levels of insulation in the walls, roofs and floors; increasing the efficiencies of windows and skylights; and reducing losses due to infiltration.

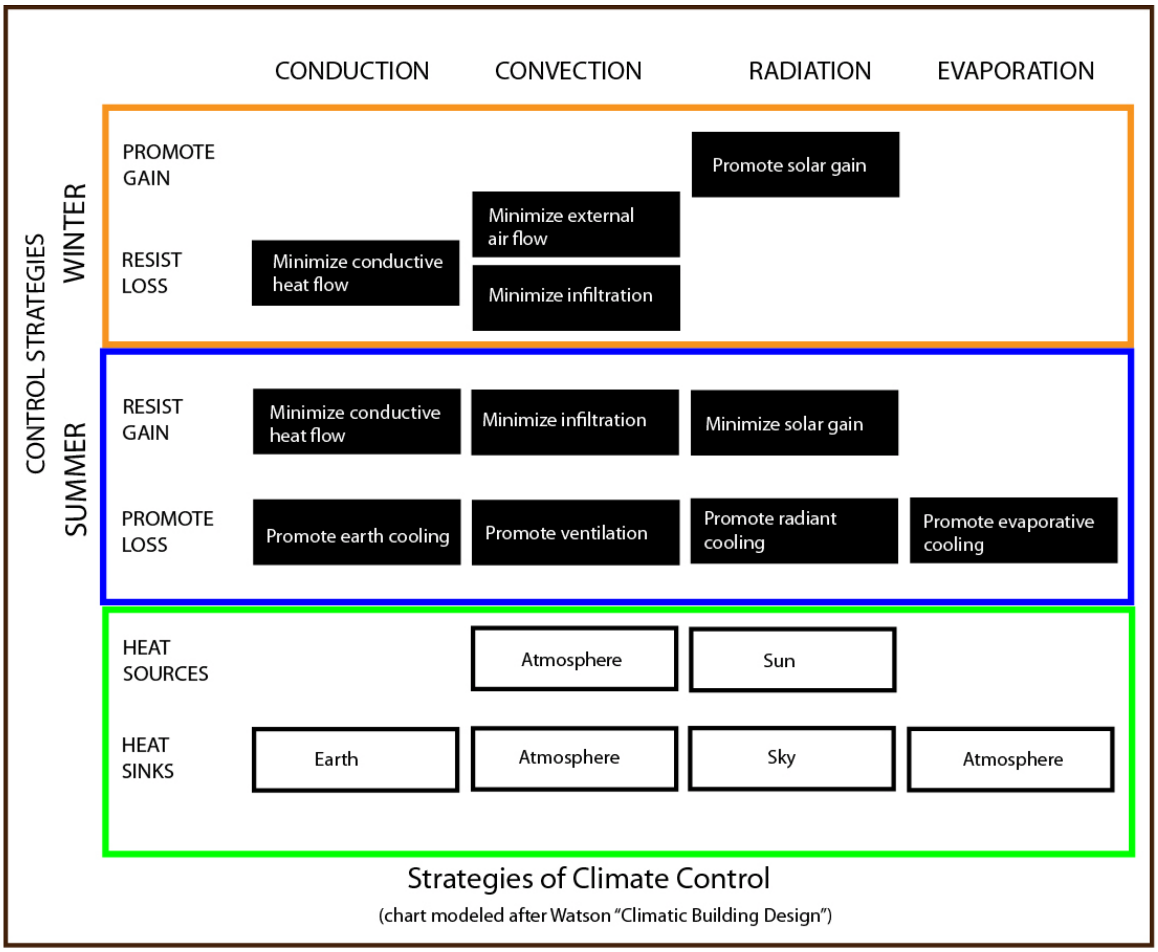

Fig 1: Passive Strategies of Climate Control

Differentiated Façade Design

One of the most obvious "signs" of a low energy or seriously sustainable building design is the differentiated façade. Climate based decisions will naturally take solar orientation into account as this impacts heat gain potential and shading design to resist solar gain to lower cooling requirements. Each orientation of a building must be physically designed in a different way to resist or promote solar gain. *This will mean differentiated façade design for south, east/west and north elevations.* This does not infer that each façade must achieve equivalent thermal resistance values, but that the building façades must balance to work towards overall energy reductions.

Truly accounting for the impact of the sun on each building façade could result in differentiated window to wall ratios on each façade. As per more vernacular/passive practices, windows on the north façade should be limited to prevent excessive gains. If larger windows are required to meet “use” objectives, then the glazing specified for the north façade should be of a lower U-value/type to offset the losses and target a better balance with the state of the potentially better performing south façade. East and west façades will have different issues due to low sun angles that might not require as much of a reduction in glass but shading that blocks low angle gains.

The variance in shading device design on elevations will present unique detailing challenges for the building envelope. Where lighter weight devices may be supported by glazing mullion systems, heavier shades will need to be attached back to the structure, thereby puncturing the thermal envelope and creating potential for heat loss and interruptions to the air barrier. Shading devices need to be designed to resist movement due to high winds that could loosen the connections and again disturb the air and thermal barriers. Shading devices also provide ledges for the build up of snow and ice in the winter months, which at times of melting can bring unwanted moisture into contact with the envelope. This can result in staining or deterioration of the envelope.

Although not necessarily apparent from the exterior, different orientations may incorporate varying levels and types of insulation to assist in balancing the net thermal resistance of each façade. This may require modifications in the construction of each façade to provide adequate depth to contain the insulation.

Insulation Requirements

Insulation levels for Residential Part 9 buildings were established many decades ago and have not been *substantially* increased. Air tightness requirements were introduced in the 1980s and practices have not been *substantially* improved. At the time the thought was that an increase above an R value of 19 in a wall, assuming the use of fiberglass batt insulation, would not result in enough reduction in heating costs to offset the additional costs of the insulation as well as the potential increase in the expense of the wall itself that would house the increased thickness. To switch to a more effective insulation type in order to maintain the framing size was also considered beyond reasonable payback. Fuel costs are many times those that were in effect at the time of the writing of the “R19”code. Additionally we are not only looking at increased fuel costs, but as well the potential for the complete depletion of fossil fuel types in the next century that will necessarily shift us towards the use of renewable energy. Renewable energy is simultaneously infinite and finite. Renewable energy is infinite in terms of the ability of the sun to continue to shine and the wind to blow, but finite in terms of the amounts that can be generated on a per building basis to satisfy present consumption patterns. Parameters have changed.

As buildings begin to use higher levels of renewable energy, there will be a shift from the use of gas and oil to electricity. At present the use of electricity to heat a Residential Building that falls under Part 9 of the Building Code automatically results in increased Code requirements for insulation. (Current proposals are moving to eliminate this fuel type differentiated approach).

Subsection 12.3.2 - Thermal Insulation

Mininum thermal insulation requirements:

2006-2011 only	Ontario South – In force		Ontario North – in force	
	Gas/Oil	Electrical	Gas/Oil	Electrical
Wall	R19	R29	R24	R29
Ceiling	R40	R50	R40	R50
Basement	R12	R19	R12	R19

Fig 2: OBC Part 12: Resource Conservation
http://www.mah.gov.on.ca/AssetFactory.aspx?did=8308 (accessed November 13, 2010)

Current practices in the design of Carbon Neutral buildings for cold climates (most of which use electricity to operate their heating systems) are working with *double code level insulation levels* as a starting point for their envelope design. As Carbon Neutral buildings are not yet common, there are inadequate case studies to provide more than rough practice information to this point. Each Carbon Neutral building has undergone unique design and energy calculation to arrive at the best method to reduce heat losses and promote heat gains for their geographic location.

Double insulation levels, considering the use of electricity could be projected to sit somewhere between current requirements noted in Figure 2. If looking at the required modification to current low rise residential wood frame construction, a substantial increase in the overall thickness of the wall could result if material choices do not change. To double fiberglass batt insulation could take the required cavity from 140 mm to 280 mm. An increase in the wall stud from a 38 x 140 to a 38 x 289 to accommodate insulation would appear ludicrous. It would provide a structure far in excess of what is required and escalate the material costs for the structure as well as labour costs. Moving framing spacing from 400 mm to 600 mm to reduce the frequency of the studs (and their decrease in thermal resistance – which would be exacerbated in contrast to the increased efficiency of the thicker wall) would require increases in the thickness of sheathing and gypsum board. This proved to be a problem when house framing initially moved from 38 x 89 to 38 x 140. The housing industry worked with 600 mm stud spacing for a short time and found the increased board thicknesses difficult for the trades. They were subsequently abandoned in favour of 400 mm spacings. As the weight of these board products has not decreased it would be safe to assume that it would meet the same resistance today.

Thicker walls take up more floor area. Larger houses would not see as drastic a decrease in the percentage of usable floor area as smaller buildings, but this would also be a disincentive. To accommodate double R values for walls then necessarily infers significant change in construction methods and choices in insulation. More costly sprayed insulations and insulating board products that allow for smaller structural members begin to make sense.

The Aldo Leopold Legacy Centre, one of the first Carbon Neutral buildings in the United States, is located in Wisconsin and has 7643 HDD ^{o}F and 193 CDD ^{o}F. The complex is constructed around a solar meadow to allow for direct gain into the primary buildings and good solar access for the expanse of PV that services the off grid facility. This small institutional project uses highly differentiated façades, both in appearance and wall detailing, to meet the requirements for heating, cooling and daylighting for the varying functions of the plan. Unlike a residential occupancy where daylighting is less critical, the Leopold Centre includes office use and works to the elimination of electric lighting during the daytime hours. The project is completely framed in wood, and its approach to detailing could serve as a test precedent for modifications to current less energy efficient framing practices.

Fig 3: Aldo Leopold Legacy Centre, Barabou, Wisconsin

Fig 4: Aldo Leopold Legacy Centre – Wall Types

The project has abandoned the use of traditional fiberglass batt insulation in deference to sprayed insulation (cellulose) and SIP panels. The project uses Weather Blanket Cellulose insulation, which advertises an R value of 32 for a 200mm thickness. The stud sizes are in the 200mm range to accommodate the increased amounts of insulation deemed necessary to reduce heat loss. The layout also varies the wall type and amount of insulation as a function of building orientation. SIP panels are used on Wall Type B (which faces north) for the added performance and decrease in reductions of efficiency due to wood studs. The balance of the exterior walls in parts of the building that are not highly glazed to prioritize solar gain, (Wall Type D) also have an additional layer of rigid insulation to reduce conductive losses due to the wood studs.

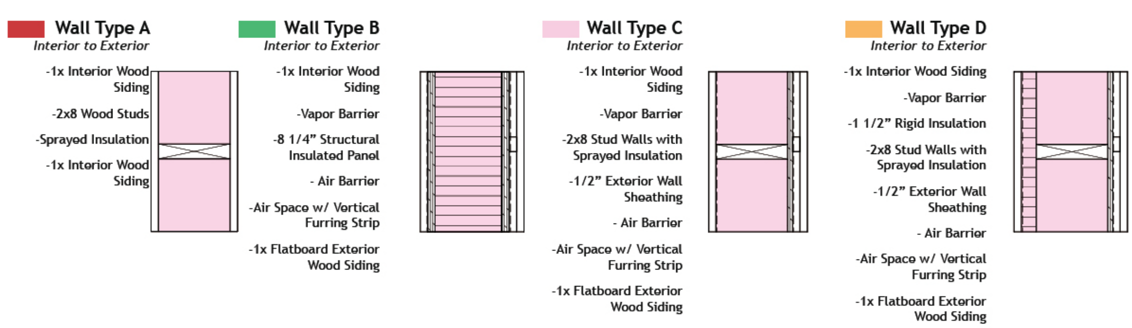

Fig 5: Aldo Leopold Wall Types

Skin load dominated buildings using light steel framing will have to assume similar differentiated approaches to adjusting the overall insulation levels for façades, but due to their conductive nature will always require an extra layer of rigid insulation on the cold side of the wall to limit the conductive losses due to the metal studs. Many new types of extra deep stud types are presently being manufactured that use a truss type web in order to limit the amount of steel in the wall, reduce the path, and allow sprayed in place insulation to be almost continuous through the wall assembly.

Fig 5: These steel studs, manufactured by Steelform Building Products, are available in widths to 200mm. Sprayed insulation can form around the metal, which has also been made thinner – possible due to the shaping of the material.

When choosing insulation it is important not only to choose one that will provide more R value per unit thickness but also to consider its material properties as impacts embodied energy and low VOC requirements. Various types of spray foam insulation have the added benefit of providing an air barrier and also reducing losses due to infiltration. Soya based sprayed foam materials also begin to address embodied energy and renewable resource questions.

Glazing Requirements and Natural Ventilation:

Glazing presents very different issues when comparing skin load dominated buildings and interior load dominated buildings. Typically skin load dominated buildings use windows selectively as perforations to the envelope to provide some daylight and natural ventilation, where interior load buildings use large expanses of glass to provide more effective daylighting and not always significant natural ventilation. Although the inclusion of natural ventilation in commercial buildings is increasing due to pressures placed by green building assessment credits, the amount of operators is seldom sufficient to allow for the complete elimination of A/C. There are additional acoustic concerns attached to the use of operable windows in high rise urban situations. Noise generated at grade seems louder as it carries through open windows on upper floors of buildings. Where ventilation sees a breeze become a wind force, this can also cause disruption to office type uses.

Where low rise residential windows must provide for large enough openings to permit egress in case of fire, most high rise windows are limited to 100mm openings to prevent occupants from fatal falls. This presents great difficulty if looking to provide enough ventilation to exclude an A/C system. This issue is acknowledged as being critical in the design of long term care facilities, which although following skin load dominated design for the most part, and even if low rise in scale, must follow the 100mm limitation on operators due to incidences of fatal falls.

The move towards increased natural ventilation presents a significant design issue for the building envelope if openings in excess of 100mm are desired. More frequent operators could be one solution, but this would substantially increase the costs of the envelope and could potentially result in increased infiltration issues for winter conditions, particularly if the weather seals age and deteriorate. High rise residences can accommodate larger openings by placing them at exterior balconies, or by providing railings (as in French balconies).

Commercial buildings may need to look at similar design strategies to increase the operability of the envelope, but this will bring with it problems with acoustics and wind speed. Many European High Performance Buildings are looking to double façade design to allow for better and more controlled natural ventilation strategies. These façades also provide weather protection for shading devices and create a more complex path to control wind speed and urban noise. These types of façades are less common in North America due to their expense and requirements for design expertise. Their ultimate benefit is highly contested as a function of both cost as well as significant increases in embodied energy (double the wall, double the embodied energy). Detailed simulations are required and the mechanical heating and cooling systems must be downsized in accord for double façade systems to approach the performance levels required to work towards a true low energy solution.

Thermal insulation requirements are somewhat simpler in that it is more an issue of specification than a significant alteration in the way a building is designed. Windows present a discontinuity in the thermal value of an envelope and in traditional “R19” construction, normally a significant reduction in R value in comparison to adjacent walls. In Low Carbon design that looks to double code thermal resistance values for opaque construction, this presents an increased challenge for transparent elements.

The generally accepted rule of practice for glazing a Low Carbon building in a cold climate for a single façade building will be to specify triple glazed, low e, argon filled windows with non-conductive spacers and a low conductivity frame. Where passive gains on south exposures may be a priority, this might be altered to permit more solar penetration, provided that adequate summer shading is also provided to prevent excessive summer gains. As passive cooling will also be a priority, operable panels must also be maximized. This puts added pressure on sourcing quality windows as the weather seal around operators must not permit infiltration. Additionally, the amount of operable window area will have to be upsized to account for ventilation losses that result from insect screens. These screens will reduce air flow by around 50%.

In cold climates glazed elements, no matter how well-designed, result in high levels of heat loss during dark hours. Envelope design needs to also consider the inclusion of night insulation to reduce these losses.

Passive Heating and Cooling:

Thermal Mass:

Building and subsequently envelope design has evolved since the advent of mechanical heating and cooling, to disregard the benefits associated with passive systems. In simple terms for low rise residential design this has meant insufficient thermal mass on the interior of the building to store the free energy from the sun and buffer against summer overheating. Standard frame house construction (in wood or light steel) will typically finish the interior in gypsum board, which is insufficient. Thermal mass on the interior needs to be supplied by changing to exposed concrete or heavy set tile flooring that can store this energy, potentially the use of masonry products on the interior wall finish of a building, or a combination of these strategies. Where it is unlikely that exposed masonry will become the norm for interior wall finishes, the trend towards concrete in floors that work in conjunction with radiant heating systems is on the rise. This may decrease pressure on the envelope to change to assume this role. Thermal mass on the interior combined with double code insulation levels could result in walls that are excessively thick and difficult or prohibitively expensive to construct.

For commercial or institutional buildings that currently use masonry on the interior, current practice supports passive design if the window areas are also upsized to allow for adequate solar gains. High-rise residential buildings already make good use of exposed concrete due to their construction type.

Designing for Solar Gain:

The façades will need to be constructed to maximize passive design, including the use of solar energy for heating so to minimize requirements for additional mechanical heating. All southern windows would have seasonal shading geometry, so they would be shaded in summer, but not in winter. East, west and north glazing would also need to be controlled for heating and cooling.

Overhangs to protect windows from summer solar gains will have the added benefit of providing walls on low rise buildings with some protection from rain and wetting. The structural support of shading devices adds complications to the construction of the envelope as a function of the transfer of loads and provision for attachments that do not create thermal bridges.

Daylighting:

The need for quality daylighting creates a distinction between the envelope design for commercial/institutional occupancies and residential occupancies. While residential occupancies can benefit by daylighting, this can often be accomplished without a large reduction in the insulation performance of the envelope due to a high window to wall ratio. This is where low carbon design would see an adjustment to current high-rise residential design practices. Given the predominance of concrete frame construction (and potential for exposed concrete/thermal mass) for this type, larger window areas might be able to be justified (numerically proven) if high performance glazing systems are used and night insulation provided.

Fig 6: Double façade office building in Berlin, Germany. The exterior glass skin is not sealed and allows for migration of ventilating air to the interior while buffering noise. The interior façade is not fully glazed and includes opaque thermal elements with frequent operable windows.

Balancing the energy benefits of daylighting versus the heat loss (winter) and solar gain (summer) issues associated with the glass sits at the center when it comes to assessing the envelope design for commercial office occupancies. This is where energy simulation for the whole building is essential to balance the benefits and detriments of shifting changes in the window to wall ratio. Although not a direct concern in the design of the envelope it is critical to note that daylighting is of no energy benefit at all if energy efficient light fixtures are not specified and combined with effective dimming practices. The dimming mechanisms should be zoned to allow for differentiated dimming for floor areas directly adjacent to windows, those 5 metres away and those areas that are sufficiently distant from windows to have no daylighting benefit. Ideally buildings should be designed with a thin plan that eliminates areas that cannot be daylit. This is legislated in Germany and as a result gives rise to commercial office design that maximizes useful and energy efficient daylighting.

The bottom line for such comparative value assessments is to keep sight of the Net Zero energy target and fine tune the simulation model and building design to optimize the design of glazing for daylighting with the design of the envelope for passive heating and cooling related energy reductions.

TARGETING EMBODIED ENERGY

Embodied energy is not the top priority in current Low Carbon practices as it represents a smaller part of the GHG problem. However, when operating energy is effectively reduced, embodied energy will de facto become a very large part of the remaining problem. Every material specified in the envelope needs to be analyzed for its embodied energy:

- due to manufacturing
- due to transportation to the manufacturing site
- due to transportation to the building site
- due to fuel spent for construction
- due to equipment needs for installation
- due to the relative amount of time for construction given that if installation is quicker there may be energy benefits

The consideration of embodied energy will be almost identical for interior and skin load dominated buildings. Where the material choices may differ will result from the assessment of priorities to reduce heating, cooling and lighting loads from the respective buildings which may alter the window to wall ratio which feeds directly into material choices.

The calculation of the embodied energy of the building as it relates to achieving low carbon is *not* straightforward. Most common methods will account for issues of transportation and material manufacturing but do not look at the synergistic aspects of material choice as it feeds into passive heating and cooling efficiencies. Such calculation requires a high level of computation that is based on the combination of energy performance, climate/region, as well as material specifications. There are aspects of envelope design that are difficult to separate from their carbon impact on the overall performance of the building as well as manufacturing and transportation implications for the project in general. There are some recently launched tools such as the Athena Impact Estimator for Buildings[i] as well as the Athena Eco Calculator[ii], both of which are useful in calculating more specific environmental impacts that include CO_2 as well as other emissions.

Site and Location Issues:

It may prove easier to manufacture or fabricate low embodied energy building components than to achieve the same reductions on site by modifying current construction practices. Manufacturing facilities may be able to be operated using Green Power or renewable to generate their own power needs. A higher level of prefabrication of the envelope elements may assist in reducing carbon.

To achieve a truly carbon neutral state, all building envelope materials must be brought to the site by vehicles powered by either bio-fuel or electricity that has been generated in a sustainable fashion. All power tools used to construct the envelope would be powered by energy cleanly generated. This would require the use of solar or wind power or by generators powered by bio-fuel. If using electricity from the grid, it would be supplied by renewable sources ("Green Power").

Concrete would only be used if it was manufactured using renewable energy, and the carbon dioxide from cement production was sequestered. Flyash may be used to offset some of the cement content in that this assists in reducing the net carbon cost of another industry and is a waste product. The use of concrete would be limited to those elements where it is structurally necessary, as in foundations, or where its thermal mass value is essential to the passive design strategies or systems.

The building envelope materials would either be locally manufactured, from sustainably forested lumber, milled using renewably-powered sawmills, or would be recycled. Locally grown wood, recycled metal and glass and local clays or cob could be used. This will make use of some information already gathered in the associated LEED™ credits.

Synergies that Justify Use:

The use of other manufactured materials that have high embodied energy, such as aluminum for curtain wall, glass, metals, plastics, etcetera, would reduce the carbon neutrality of the building by initial calculation – but could be justified if the use of these materials fed into the increased efficiency of passive heating, cooling and daylighting strategies. Much like the production of concrete, their manufacturing processes would be held accountable to the carbon neutral equation. To balance their carbon "expense" it would be necessary to design the building (project – so this could include site development strategies and landscape) to convert some of the CO_2 cost into oxygen, or to illustrate their part in the effectiveness of reductions in operating energy. This aspect of qualification is far more stringent than LEED™ which awards credits for low VOC materials but does not address any aspect of their carbon production. For instance, a LEED™ credit is earned for using low VOC carpet, but there is not a reward for avoiding its use, which would be preferable in the long term.

Waste and Durability:

No construction or demolition debris should be land filled or be transported from the site. Therefore any waste or scraps would be required to have a designed "use" or "place" in the project.

Durability is of primary concern to justify the embodied energy of the building envelope as it feeds into the issue of "future waste". Where it is unlikely that structural elements will need to be replaced over the life of the building, envelope components are designed with a lifespan and if this is short can result in high levels of GHG emissions. The building envelope would need to be constructed so that it could be expected to last for 50-100 years, and if it required to be demolished, the materials could all be reused, easily recycled, or returned to the earth as in composting.

When specifying elements for the envelope, particularly cladding materials and windows, Life Cycle Analysis, combined with an embodied carbon analysis, is required to assist in justifying the extra expense often found in the cost of more durable systems.

This feeds well into Cradle 2 Cradle[iii] ideologies and Design for Disassembly methods. C2C supposes that no part of the building should ever become land fill and either be recycled as a Technical Nutrient or Biological Nutrient or reused. This requires that envelope elements, during repair or demolition, are designed to "come apart" in a relatively non destructive fashion. This will allow for separation of materials to feed into the three streams. Design for Disassembly will require a re-visioning of the construction of the envelope in order to maximize the number of components that can be simply reused at the point of deconstruction (thereby reducing additional energy that would be required for recycling), versus those that can be separated out for recycling.

This type of assembled methodology can begin to radically change the way that envelopes are designed and detailed as assembly and potentially prefabrication techniques merge with requirements for continuity of air barrier systems and closure of air leakage paths between elements.

CONCLUSION:

Decisions made in the design and detailing of the building envelope feed directly into the potential for an effective Low Carbon to Carbon Neutral design solution. As demonstrated the envelope directly influences the potential for significant reductions in operating energy through its attitude towards the inclusion of passive heating, cooling and daylighting strategies that look back to indigenous and vernacular typologies that pre-date the widespread introduction of mechanical and electrical systems

The issue of carbon associate with the embodied energy of envelope materials may not currently be a high priority, but changes that are fed into the current work to redesign the envelope to assist in achieving low carbon targets will benefit if embodied energy issues are simultaneously addressed.

Both operating and embodied energy concerns require that current approaches to detailing and designing envelopes be reassessed, and for many building types, this may mean massive change and the abandonment of the current status quo. This will particularly impact current practices in skin load dominated buildings versus interior load dominated buildings where envelope design is currently not reflecting the actual needs of the use for access to daylighting versus priorities for heating and cooling.

Simulation is an absolute necessity in achieving a verifiable balance between passive heating, passive cooling and daylighting priorities as we target the reduction of our use of fossil fuels to zero.

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[i] Athena Institute Web site http://www.athenasmi.ca/tools/docs/ImpactEstimatorFactSheet.pdf
[ii] Athena Institute Web site http://www.athenasmi.ca/tools/ecoCalculator/index.html
[iii] http://www.mcdonough.com/cradle_to_cradle.htm