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Computer Software for Building Envelope Design

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Abstract

One of the ideas that CSC's 1992 Conference emphasized was the need to reduce the energy use of buildings. With building envelopes there are two ways to do this. One is to control heat gains and losses, and to control movement of moisture (and latent heat with it), without undue expenditure of embodied energy. The other is to design buildings so that the end of their useful life is not dictated by premature deterioration, again without undue capital expense in embodied energy. Although the physics required to predict flows of moisture and heat is well understood, we don't know enough about material properties, environmental loads, and limit states to answer questions like "how much air leakage will a double wythe masonry wall with 150 mm of XEPS tolerate without damage, if the building is in Yellowknife and houses a swimming pool?" We know it will have to be uncommonly airtight, but what does that mean in (L) (s^{-1}) (m^{-2}) at 75 Pa, and how hard will it be to achieve? We know enough about properties of materials, expected loads, and limit states to design that same wall structurally with confidence that we are neither wasting material, nor risking premature failure. But, we are only just beginning to collect the information needed to apply the physics of heat and moisture, or the biology and chemistry of deterioration, to envelope design in the way we already apply structural mechanics to the structural design. Only when we have that information, and tools with which to use it, can we design novel building envelopes. And, only then will we be able to put successful building envelopes into novel service conditions without unexpected failure, waste of resources, or both. Premature failure due to structural inadequacy is rare. Premature failure due to moisture-induced deterioration is not. This presentation will review some of the research programs that are underway, and computer programs that have been written to apply the results, and then focus on several examples of how building envelope details can be better understood and improved by using 3D finite element heat flow software. The examples include thermal bridges large (slab edges) and small (brick ties), and insulation of foundations to compensate for insulation under slab on grade.

Synopsis

The world is rapidly reaching the point in exploitation of fossil energy reserves where rates of production on a world-wide basis will begin to decline. No one knows exactly when production will peak, but it will, and best estimates are that this will happen sometime between 2010 and 2020. Renewable energy sources have yet to become capable as technologies - photovoltaic panels, for instance, still manage to collect in a life of service only about as much energy as was required to manufacture them. Fission is not a viable source - we already have more Plutonium than we can figure out how to store safely.

Soon, we are going to have to fine-tune building envelopes so that they do not use more energy than intended, and do not deteriorate prematurely. Overdesign needs to be avoided to, since it wastes embodied energy. Buildings will have to be more predictable in service life, and in total energy consumed by both concstruction and operation. We will also have to measure building costs in physical units of mass and energy, rather than monetary units, because this will allow our knowledge of costs to grow, rather than having to be scrapped each time the value of money and the interest rates that determine net present value change. The present value of 1 Joule 10 or 20 years from now is about 1 Joule (increases in efficiency of use might make it worth somewhat more), whereas predictions of it's monetary value are highly unreliable because of fluctuating prices and interest rates.

For building envelopes, moving from our present procedures, basically trial and error with a bias toward overdesign, to something like the limit states model used for structural design will become necessary. This will require better understanding of how envelopes respond to environmental loads. The basic physics of heat movement, air movement, and wind are known - but hard to apply to complex situations. As with structural design, computerized models will make quantitative analysis much easier, and allow us to understand things that are otherwise too complicated to contemplate. Although required knowledge of environmental loads is spotty and needs to be extended, and although our knowledge of properties of materials is likewise not yet sufficiently detailed, much software has emerged in the last decade that can be applied to analysis of building envelope designs. This software includes computational fluid dynamics, heat flow, moisture transport, air leakage, and radiation. To fill gaps in our knowledge of material properties and limit states, work is ongoing at places like ORNL, FORINTEC and IRC . Many of the available programs are free - the only cost is learning how to use them.

The presentation briefly reviews what we can model, and what models are available for application to building envelopes, and then examines several applications of HEAT3, a 3-dimensional, transient or steady state, finite element program that models heat flow by conduction. The models truly cross borders - having origins in Canada, the USA, Germany, and Sweden, to name only a few. Heat3 is a product of Blocon Software in Lund Sweden, an outgrowth of the Building Physics program at the University of Lund.

What can we model?

- whole building operating energy
- wind & air pressure
- rain deposition patterns
- vapour diffusion
- air leakage
- cavity pressure equaliztion
- capillary moisture
- effects of salts and surfactants
- latent heat & phase change in materials
- thermal mass
- radiation ~ light and heat
- heat conduction
- convection

What Programs are availble?

- Twist ~ CFD
- WDRain ~ Rain Deposition
- Fluent ~ CFD & Rain Deposition
- Hot 2000 ~whole building energy simulation lite
- DOE2 ~ whole building energy simulation (more comprehensive)
- RAIN ~ dynamic cavity pressure equalization
- EMPTIED ~ annual cycle of condensation from air leakage and diffusion
- SHAM ~ simplified Hygrothermal Analysis Method ~ an extension of EMPTIED
- OPTICS ~ light and heat transfer of multiple layered vision lights
- FRAME 5.0 ~ 2D steady state heat flow by conduction
- THERM 2.1 ~ 2D steady state heat flow by conduction
- HEAT2 ~ 2D steady state and transient heat flow by conduction, with internal heat sources, fluid filled cavities, and radiant exchange in cavities.
- HEAT3 ~ 3D steady state and transient heat flow by conduction
- HEAT 7.2 (ORNL) ~ 3D steady state or transient heat flow by conduction
- WUFI-ORNL ~ 2D transient heat flow and moisture flow with air leakage and rain
- hygIRC ~ 2D transient heat conduction, radiant flux, rain, air and moisture movement
- Walldry ~ transient, moisture by diffusion, heat by conduction, condensation & drying due to air leakage and ventilation
- MOIST ~ one-dimensional, transient, vapour by diffusion, capillary storage and transport, heat by conduction and enthalpy

For an extensive review of heat air and moisture models, see “Review of Modeling Methods for Building Enclosure Design” byDr. John Straube and Dr. Eric Burnett, available from http://www.buildingsolutions.ca/Downloads as “HAM Modeling Review.PDF”.

3D Heat Conduction Examples

Side-mounted BVSS brick ties

Steel studs are known thermal bridges that lead to dust marking and perhaps condensation on interior surfaces, in addition to substantial heat loss. It is often recommended, at the least, to add insulating sheathing to the outside of SS exterior walls. When walls are clad with brick, do side mounted brick ties make a big difference to condensation and heat loss problems? Do holes in the tie in line with the insulation help? What if the stud space is not insulated?

In a model of a BVSS wall, with 92 x 2 mm steel studs at 600 mm centres, gypsum board inside and out, mineral wool in the stud space if insulated, and 50 mm of EPS on the outside, 1.6 x 50 mm side-mounted ties spaced at 400 mm centres perform as follows:

	% of total heat loss thru ties	Temperature Index of tie in stud space, min.
Plain tie, studs insulated	11	.64
Plain tie, studs uninsulated	8.8	.84
Perforated tie, studs insulated	10	.66
Perforated tie, studs uninsulated	7.5	.86

Ledger angle for a BVSS wall

It has been advocated by building envelope specialists to shim and grout ledger angles to concrete slabs, because the resulting heating of the exterior helps to keep the wall cavity free of moisture problems - is this a good idea?

We tried two 3D steady state models of a wall supported on edges of 200 mm concrete slabs, with 92 x 2 mm metal studs at 600 mm centres, and 1220 mm floor to ceiling. The wall was insulated with mineral wool in the stud space, plus 50 mm of EPS on the outside. The vertical face of the 102 x 102 x 8 mm ledger is in line with the exterior face of insulation. In one case the ledger is suported with shims and grout, so that the slab is, in effect, in contact with the back of the ledger. In the second case, the slab stops in line with the exterior sheathing, and the ledger is supported on 10 x 102 mm knife plates at 1200 mm centres, so that there is insulation behind most of the ledger. This was the result:

	% of total wall heat loss thru ledger	Temperature Index of stud track, min.
Warm ledger	40%	.53
Cold ledger	19%	.72

HSS penetration of an insulated wall

If a heavy structural member passes through an exterior wall, exposed to both interior and exterior, what can be done to prevent condensation on the interior? This model was made to determine how to prevent condensation in this situation, with high indoor humidity. One way is to add insulation to the exterior, extending out around the member for a significant distance. The other is to add a “radiator fin” to the interior side, to collect heat and keep the member warm - not an energy wise solution, but perhaps desirable for the designer who prefers a robust look, with the steel structure fully exposed inside and out. In the models, the structural member is a 120 x 120 x 10 HSS. One version (sock outside) has the outside covered for 500 mm away from the wall with 25 mm insulation, in addition to filling the inside of the tube. The other (fin inside) has a 200 x 200 x 10 mm steel fin on the tube at the interior. The following are the results:

	heat flow through HSS, W/°C	Temperature Index Interior, min.
Sock outside	0.107	.74
Fin inside	out of bounds > 0.4 ?	.74

Foundation insulation to compensate for insulation under slab-on-grade

Adding insulation under slab on grade is a great energy-saving idea, especially for hydronic heated slabs. Beaver Plastics have a molded insulation for sub-slab use that also acts as a chair for the heating tubes, but customers fear that their foundations may freeze. Working with Jacques Whitford, using transient 3D models, we determined that for every thickness of subgrade insulation, there is a reasonable configuration of exterior subgrade insulation that can ensure that the minimum annual footing temperature is no lower for the insulated configuration, if the footing conforms to required depth requirements for uninsulated foundations adjoining a heated building. We also observed that temperatures are much lower at exterior corners and projections (places where we know some buildings have trouble with frost heave) and that 3D models can help to devise added protection for these locations. Design tables for thicknesses of sub-slab insulation up to 100 mm will be available for several Alberta cities from Beaver Plastics.

Copies of this presentation are not included in the conference binder because most of the slides are meaningful only in colour. We will endeavour to post a PDF version of the slides on the Web (but have not made arrangements to date). If you have a high speed connection, and are interested, contact the author at <jpo@canuck.com>. Copies can be furnished on CD, for minimal cost.

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