DOE2.1E GEOMETRIC MODELLING:
The Basic Geometric Approach vs. The Complex XYZ Approach

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ABSTRACT

The DOE2.1e energy modelling program provides different approaches for defining the geometry of a building. The simplest approach involves defining the length, width and direction of building surfaces (basic geometry approach). A more complex model involves defining the co-ordinates of all surfaces (XYZ or detailed geometry approach).

The perceived reason to use the XYZ approach is to better capture the effects of solar shading and daylighting. The XYZ approach can directly model building shades and shading from other parts of the building. However, DOE2 also provides a simple facility for defining horizontal and vertical window shading devices.

The amount of time required to model a building depends on the approach and tools available. The basic geometric approach takes less time than the XYZ approach. This paper examines the building energy use differences for two projects modelled using both approaches. It also compares building energy use and peak loading for both methods following a series of "XYZ simplification" steps.

For the two projects examined, this paper shows there is little difference in total building energy use. These specific results, as well as results from many previous DOE2 modelling projects, reveal that full XYZ geometry is seldom cost-effective.

INTRODUCTION

Building energy simulation programs come with a wide range of complexities and capabilities for accurately defining the geometry of a building design within a thermodynamic model. Some, such as Hot2000 [1], allow for a relatively basic geometric definition and a bin calculation method to model energy use. Creating a model is relatively simple; the area and facing direction of each surface are all that the model needs to capture the building geometry, as it pertains to energy use. Only surfaces of interest need to be modelled. (For example, an adiabatic wall separating units in a duplex need not be modelled if only one unit is of interest.) Others, such as ESP-r [2], are sophisticated and very complex to use. The model must be geometrically contiguous, with all surfaces defined using specific spatial coordinates, dimensions, outward orientation and surface tilt. Further, each zone must have a fully bounded volume, with surfaces joining correctly at all junctures where surface meet each other—in other words, a visually correct representation.

The DOE2.1e [3] energy simulation program (DOE2) allows for complex and/or basic geometric modelling for energy use simulation. Like ESP-r, the user can completely define each surface with its geometric location by using x, y ,z coordinates, defined using a right-hand coordinate system (XYZ approach). Or, the user can define surfaces simply by specifying the area and facing direction (the basic geometric approach). In both cases, the orientation and tilt of walls, roofs and floors are defined as well, even if by default.

The perceived reason to use the XYZ approach is to better capture the effects of solar shading. Windows, in particular, are most affected by shading devices. Hence, the XYZ approach can directly model building shades and shading from other parts of the building. However, solar shading can also be captured using DOE2's simple facility for defining window shading devices. Horizontal shading devices (overhangs) and vertical shading devices (fins) may be defined using DOE2 keywords associated with the window definition. The user usually can use the fins and overhangs to represent most external shading situations.

The time to develop the model depends on which approach is taken. The XYZ approach requires a detailed take-off of all surface coordinates, height, width and facing direction. Each surface in the model is defined by specifying its x, y, z coordinates relative to the containing space origin. Each space's origin is defined relative to the building origin, with its direction defined relative to that of the building. Finally, the surface azimuth (facing direction) then is defined relative to the azimuth of the space that contains the surface. In contrast, the basic geometric approach only requires input of the area (height and width) and azimuth of each surface. As a result, the drawing take-off time and model definition are reduced significantly.

The accuracy of the DOE2 simulation does not necessarily correlate to the geometric detail of the model. In the majority of cases, the basic geometric approach is sufficient for the desired accuracy of the results.

This paper compares DOE2 simulation results between models constructed using the complex XYZ approach and the basic geometric approach. It examines two building models using "unbundling steps." In other words, the models start with full XYZ geometry and are then modified through a number of steps. Each step logically reduces the geometric detail of the building, ending with a basic geometrically defined model. The analysis includes whole building energy results by end use. This paper also compares energy savings results for daylighting control represented using two different approaches: (1) modelled directly using DOE2's daylighting facility, and (2) approximated by using ASHRAE's daylighting power adjustment approach.

METHODOLOGY

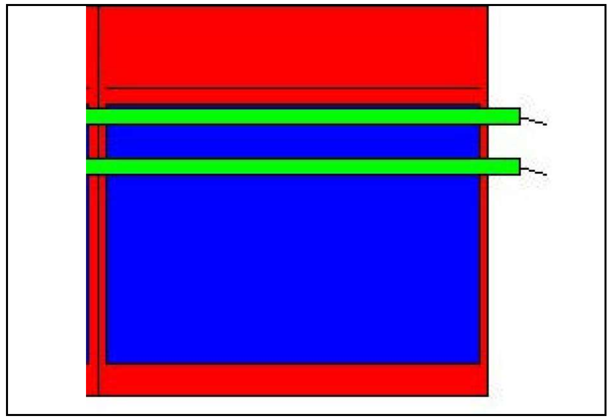
Two exiting DOE2 models, constructed using the XYZ approach, were readily available for evaluating the effects of defining the geometry at different levels of detail. The models were significantly dissimilar, thereby revealing the effects of the two modelling approaches on different building types in different weather regions.

Victoria, British Columbia Office Building

The first model was a 43,296 ft^2 (4,023 m^2) office building in Victoria. It had a unique façade consisting of a curtain wall with a briese soleil (sun shades) constructed of two, sloped horizontal shades near the top of the glazing sections (see the partial building elevation, Figure 1). The building had a narrow footprint situated in a north-south direction. Daylighting potential was high due to eight foot glazing sections. However, the southerly exposure required careful analysis in order to minimize the solar loading and glare, which are known to cause occupants to close internal window coverings.

The client requested application of the XYZ approach to examine the effects of different briese soleil configurations. This included using one, two, or three shades

Figure 1. Briese Soleil, Victoria Office Building

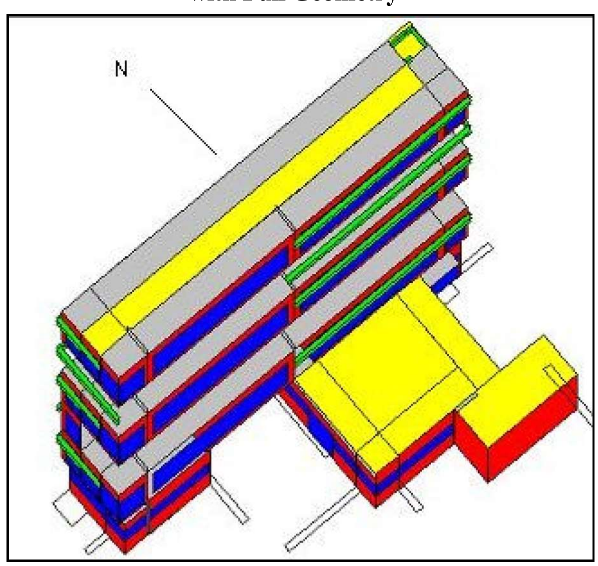


at different angles and spacing. The model described the interior surfaces in their correct locations with the presumption that this would more accurately capture daylighting savings. Additionally, the model applied internal shading (e.g., blinds or drapes) to reduce the sunlight penetration and to slightly increase the window thermal resistance. Application of the internal shading occurred only when the solar intensity or glare index reached a specified level.

Analyzing the impacts of reducing the detailed geometrical representation to a more basic model involved generating six models:

RUN 1. The original model involved creating a detailed geometrical model as described above. Figure 2 shows a visual representation of this model.

Figure 2. Office Building DOE2 Model with Full Geometry



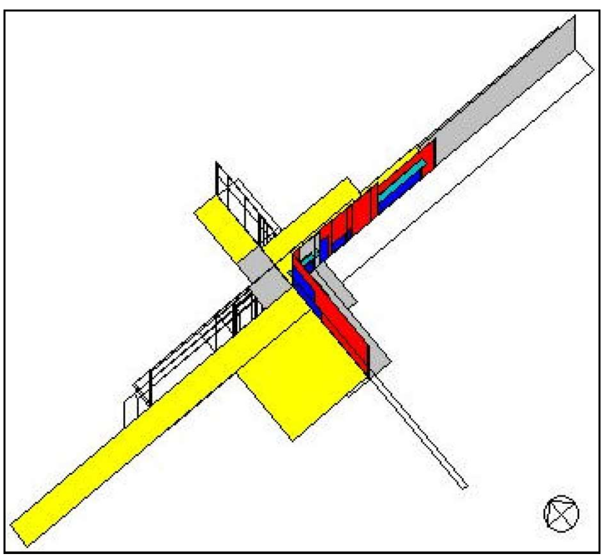
RUN 2. Beginning with the detailed model (run 1), we removed the interior surface positioning by modelling only the area and facing direction of interior surfaces. DOE2 uses a "split flux" method to model daylighting. It uses the reflectance and tilt of interior floors, ceilings and walls, but not the position of these surfaces (Winkleman, 1998).

RUN 3. Continuing from run 2, we modelled the window shading devices using the DOE2 window overhang facility. This was in contrast to the original model where the briese soleil was represented by two angled horizontal shades using the DOE2 "BUILDING-SHADE" settings. In this simplifying step, we removed the two building shades and used a single window overhang. We manually estimated the single overhang projection to represent the same window shading coverage as two building shades. The position of the overhang was set to the same position as the top building shade relative to the window. We kept the DOE2 daylighting control points in the same position as in the original model (i.e., centred in the space).

RUN 4. Using the model defined in run 3, we removed the window positioning. The window position was defined relative to the lower left corner of the containing wall. We let the window X,Y coordinates default to 0,0, thereby placing the window in the lower left corner of the wall.

RUN 5. Building off of run 4, we next removed all space and surface positioning. From a visual standpoint, the model no longer looked like the design, as shown by Figure 3. However, the model was still representative from a thermal standpoint, with the exception of some very minor self-shading on the first level.

Figure 3. Office Building DOE2 Model with Coordinates Removed



In this step we also simplified the method used to approximate the benefits of daylighting. Instead of using DOE2's daylighting facility, we used the appropriate ASHRAE power adjustment factors (PAFs) for multiple stepped dimming control. ASHRAE Standard 90.1 defines a number of lighting power adjustment factors which are used to effectively reduce the lighting load equivalently for each hour of the year. The PAF for stepped daylighting control is 0.2. In this case, 45% of the lighting load was controlled by daylighting. Hence, the weighted area power adjustment calculation resulted in a connected lighting load reduction of 9.0%.

RUN 6. We were interested in gaining an appreciation of the comparative effects of different building surface characteristics on energy use. Hence, we decided to reduce the exterior wall absorptance since specifying this value oftentimes is neglected. Using the original model in run 1, we reduced the absorptance to 0.65, which is about equivalent to unpainted concrete. The original model used a brick façade with the absorptance set to 0.88.

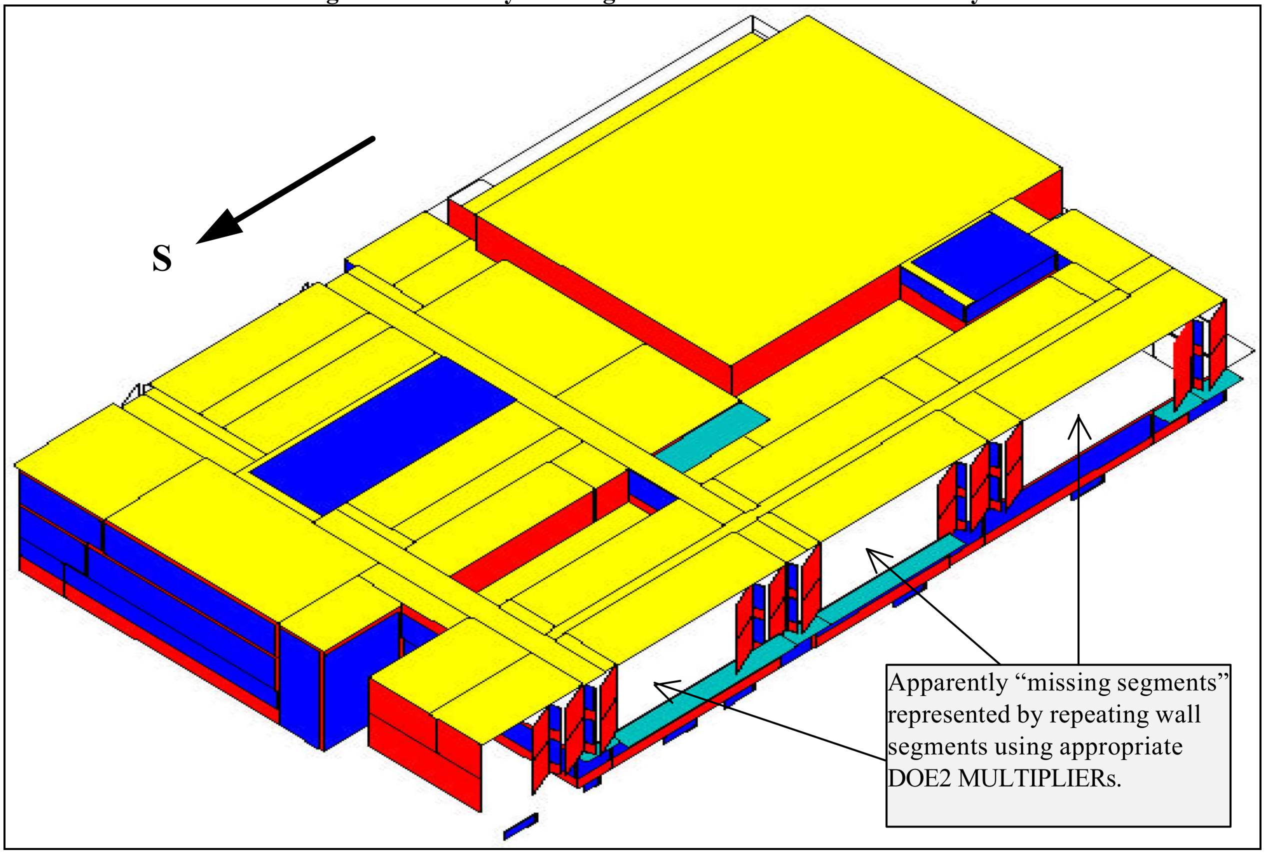
Toronto, Ontario University Building

The second project was a new 95,000 ft^2 (8,840 m^2) university computer lab building in Toronto. The design consisted of numerous teaching labs and classrooms, central corridors, and lecture theatres. Figure 6 shows how the design appeared when modelled using full geometrical input using DOE2.1e. As the figure shows, the design included several inset areas and articulated wall and window surfaces.

Our approach to analyzing the relative geometry effects on energy performance for the Toronto university building varied from the approach for the Victoria office building. First, the project did not include controlled daylighting and hence, the internal geometry for accommodating daylighting calculations was not described. Second, we thought it would be interesting to provide a relative comparison to an equivalent reference case that complied with Canada's Model National Energy Code for Buildings [4]. In summary, the analysis process followed these steps:

RUN 1. This represents the original model with the full spatial geometry represented, as shown in Figure 4.

Figure 4. University Building DOE2 Model with Full Geometry



RUN 2. We removed the window positioning, allowing the window(s) to fall to the default lower left corner position within each containing wall surface.

RUN 3. In addition to removing the window positioning (run 2), we disconnected all surface position coordinates. Hence, any self-shading of one part of the building on the other was removed.

RUN 4. We made the changes described in runs 1–3 on an equivalent reference case. This was done to compare the relative differences between the proposed design and reference case.

RESULTS

This section presents the results from the geometry simplification and sensitivity simulations for (1) the Victoria office building and (2) the Toronto university building.

Victoria Office Building

We simulated each of the six models in the Victoria office building project and extracted the energy and plant capacity results from DOE2's results reports, as listed in Table 1. Differences for each run are compared to the base case (Run 1).

Run 2, in which the positioning of the interior walls was removed, showed no difference in energy from the base case. Hence, the XYZ positioning of interior walls was not necessary, confirming that this is unnecessary for accurately modelling daylighting control.

Replacing the more exact sunshades with a representative single overhang (run 3) showed a 7% increase in cooling energy and a slight increase in heating energy. In contrast, lighting energy decreased by 4% (not shown on Table 1). The overall net effect was less than a 1% decrease in total building energy. One might expect that a building shade and an overhang of the same size and shape would have the same effect on building energy. However, the reflection of sun off the sunshades is not captured using window overhangs. Further, the overhangs are an approximation of the two building shades in this case. Note that the length, position, and depth of the overhang could be adjusted to be more representative, but that would defeat the purpose of trying to simplify the modelling process.

Table 1. Modelling Results: Victoria Office Building[1]

Model Run	Energy in mmBtu				Peak Capacities	
	Total	Heating	Cooling	Pumps, Fans	Heating (mmBtuh)	Cooling (Tons)
Run 1	2,213	458	80	646	0.76	22.8
Run 2	2,213	458	80	646	0.76	22.8
Difference:	**0 0.0%**	**0 0.0%**	**0 0.0%**	**0 0.0%**	**0 0.0%**	**0 0.0%**
Run 3	2,207	465	86	648	0.76	23.2
Difference:	**-6 -0.3%**	**7 1.4%**	**6 7.0%**	**2 0.3%**	**0 -0.4%**	**0 1.5%**
Run 4	2,218	461	87	648	0.76	23.3
Difference:	**5 0.2%**	**3 0.6%**	**6 7.3%**	**2 0.3%**	**0 -0.5%**	**0 1.8%**
Run 5	2,231	465	91	647	0.75	23.5
Difference:	**19 0.8%**	**7 1.4%**	**10 11.5%**	**1 0.2%**	**0 -1.5%**	**1 2.8%**
Run 6	2,213	461	79	646	0.76	22.7
Difference:	**1 0.0%**	**3 0.6%**	**-2 -2.4%**	**0 0.0%**	**0 0.2%**	**0 -0.7%**

Removing the window positioning in run 4 had the largest influence on cooling energy (7.8%), compared to the baseline. In addition, lighting energy increased in comparison to run 3, where the windows were appropriately positioned. This illustrates that the window position relative to the daylighting control point affects lighting energy when using DOE2's daylighting facility.

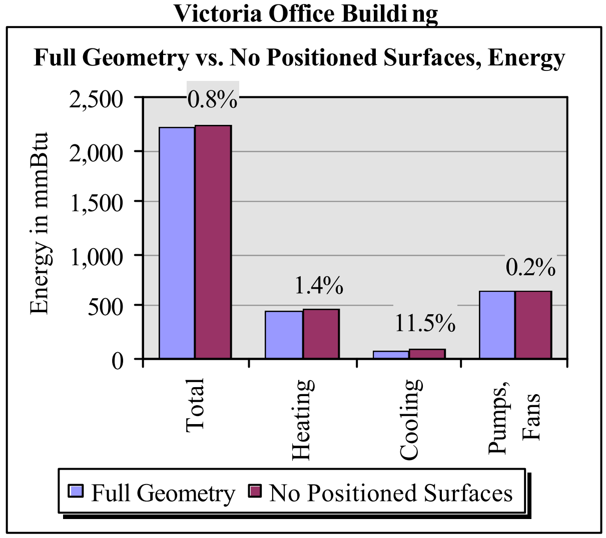
Run 5, with all wall and zone positioning removed and daylighting approximated using the appropriate power adjustment factor (PAF), increased cooling energy by 13%, yet lighting barely changed. This shows that ASHRAE's lighting PAF approach is quite reasonable for estimating lighting energy reduction due to multi-step dimming daylighting control. However, the difference in cooling energy is more than expected as the design has little self-shading modelled. In other words, one would expect that a rectangular building would have little difference in energy between XYZ positioning of the walls and no geometric positioning of the walls. Therefore, it appeared that the timing of when the lighting reduction occured affected the cooling. This made sense as the PAF applied to the lighting over the entire schedule, instead of only when daylighting opportunities existed. In contrast, DOE2 daylighting control reduced lighting primarily during periods of highest cooling demand.

Changing the wall absorptance (run 6) showed a decrease in cooling energy and an increase in heating energy. The change in the energy performance demonstrated the relative importance of this characteristic. However, in comparison to the overall total energy use, it is *also* relatively insignificant. Although it is difficult to estimate the value precisely, it is very quick to change in DOE2.

In summary, the Victoria office building project results show some difference in end use energy at each model simplification step. As expected, the cooling end uses are most affected. Because cooling is a relatively small component of the overall energy use, however, the difference in total building energy is negligible at each step. It is important to note that the difference in total building energy between the full XYZ model and the basic geometric approach is less than 1 percent.

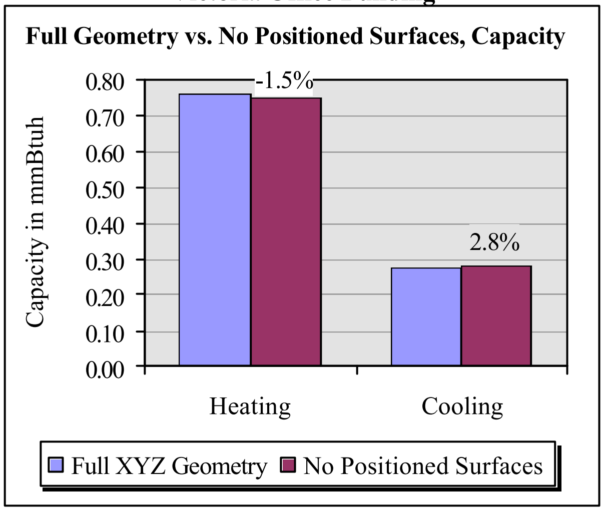
Figures 5 and 6 show the energy and capacity differences between the full XYZ model and the basic

Figure 5. Energy Use Results: Victoria Office Buildi ng



[1] The imperial units of mmBtu stands for millions of British thermal units, as directly reported by DOE2.

Figure 6. Peak Capacity Results: Victoria Office Building



geometric model. As shown in Figure 5, the total building energy increased by 0.8% when reducing the model to the basic geometric approach. The cooling energy difference is the largest, but cooling makes up the smallest part of the total building energy.

Toronto University Building

We extracted the energy and peak capacity results for each of the Toronto building modelling iterations described earlier. The energy use results were taken from the DOE2 building energy performance (BEPS) report while the peak heating and cooling capacities were derived from the equipment sizes determined by DOE2 as listed in the PV-A report.

Table 2 lists the results for the modelling runs on the proposed design in which different geometry aspects were removed (i.e., runs 1–3). As shown in this table, positioning of windows made very little difference on energy use or peak capacity. Removing all self-shading, however, made a significant percent difference on cooling energy and peak capacity, as shown in Figures 7 and 8. This change, however, is on a relatively small number. Further, these relative differences would decrease significantly if appropriate window fins were introduced as an approximation for the self-shading on the windows.

Figure 7. Energy Use Results: Toronto University Building

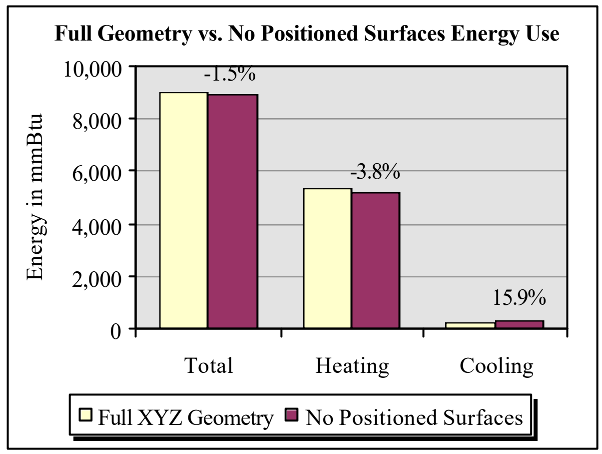
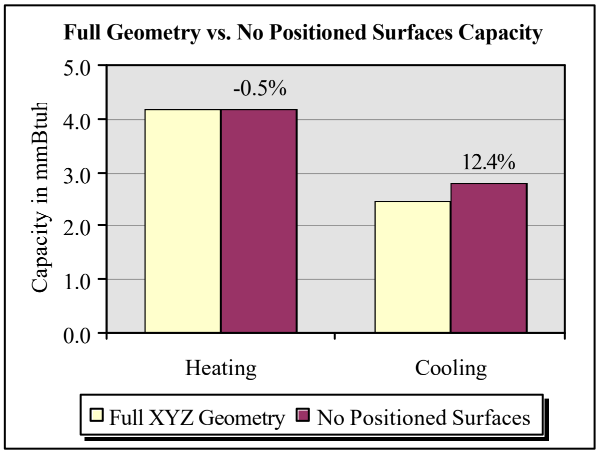


Table 2. Modelling Results: Toronto University Building

Model Run	Energy in mmBtu			Peak Capacities	
	Total	Heating	Cooling	Heating (mmBtuh)	Cooling (Tons)
1) Full Geometry	8,979	5,357	269	4.16	204
2) w/o Positioned Windows	8,990	5,372	267	4.17	202
Difference:	**10 0.1%**	**14 0.3%**	**-3 -1.0%**	**0.002 0.0%**	**-1 -0.7%**
1) Full Geometry	8,979	5,357	269	4.16	204
3) No Positioned Surfaces	8,847	5,162	321	4.14	233
Difference:	**-132 -1.5%**	**-195 -3.6%**	**51 19.0%**	**-0.021 -0.5%**	**29 14.2%**
2) w/o Positioned Windows	8,990	5,372	267	4.17	202
3) No Positioned Surfaces	8,847	5,162	321	4.14	233
Difference:	**-142 -1.6%**	**-209 -3.9%**	**54 20.2%**	**-0.023 -0.6%**	**30 15.0%**

Figure 8. Peak Capacity Results: Toronto University Building



The impact of not fully representing the geometry is much less significant on heating and relatively small overall. Once again, inputting window fins would decrease these differences further.

The final set of runs, where we repeated the three series of simulations for a comparative reference case, produced even smaller differences. The annual energy differences between the proposed case and the reference were relatively small. Heating and cooling energy differences varied by as much as 0.5% and 3.4%, respectively, for the comparison of runs 1 and 3. Total energy use differences were less than 0.005% for the same case. Changes in the heating capacity differences were negligible as well. Cooling tonnage differences, however, changed by 27 tons (5.8%).

As expected, using full spatial geometry makes the biggest difference on cooling due to solar shading. Hence, it is important to pay attention to solar shading. The effort required to input full XYZ geometry to account for these differences, however, may not be worthwhile. In the university building case, cooling only accounts for about 3.0% of the total energy use; without any spatial geometry, this rises to 3.6%. Further, unless the mechanical designer accounts for self-shading in equipment sizing (which is very rare), the exercise of fully representing the spatial geometry becomes academic.

CONCLUSION

The results show that, for the two projects presented, there is little difference in total building energy between models using a full XYZ geometry and those with a basic geometric approach, although it took approximately 30–40% longer to develop the XYZ models. Our findings with these projects, and with over 18 years of combined DOE2 modelling experience, have shown that full XYZ geometry is seldom cost effective. However, no situation is the same and, for some specialized cases, it is worth the extra effort to generate a partial (i.e., for only the surfaces affected) or full geometric model. But, in general, time is better spent focusing on other aspects. As illustrated with the wall absorptance example, the time taken to gather information about the building that is not readily available in the plans and specifications is at least as valuable and in some cases may be more important than the time taken for XYZ modelling.

The results also illustrate that the non-XYZ models tend to make the analysis conservative since cooling is most affected. HVAC designers usually favour more conservative estimates when sizing their equipment and rarely take into consideration the effect of self-shading upon the cooling load. Hence, performing full geometric modelling is usually regarded as academic from an HVAC designer's point of view.

ACKNOWLEDGEMENTS

Figures 1-6 produced using DrawBDL, Joe Huang and Associates, 6720 Potrero Avenue, El Cerrito, CA 94530 Ph/Fax: 510-236-9238.

REFERENCES

Winkleman, Fred (1998), *Building Energy Simulation User News, Vol. 19, No. 1*, Lawrence Berkeley Laboratories.

END NOTES

1 Hot2000 is developed by Canmet Energy Technology Centre, http://www.nrcan.gc.ca/es/etb/cetc/cetchome.htm.
2 ESP-r is developed by the Energy Systems Research Unit, University of Strathclyde, Glasgow, Scotland, http://esru.strath.ac.uk/.
3 DOE2.1e is developed by Lawrence Berkeley National Laboratory, Hirsch & Associates, Consultants Computation Bureau, Los Alamos National Laboratory, Argonne National Laboratory and University of Paris, http://gundog.lbl.gov.
4 *Model National Energy Code of Canada for Buildings*, 1997, Ottawa: National Research Council of Canada.