SIMPSON GUMPERTZ & HEGER
Engineering of Structures and Building Enclosures

Modeling Complex Geometries in Whole Building Energy Simulations

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Learning Objectives

1. Review industry guidelines on geometry detail for energy models.
2. Understand the effect of increasing model geometry detail on simulation results.
3. Develop a rule-of-thumb for the level of detail of energy model geometry required to accurately represent building with complex geometry.

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Complex Geometries are Commonplace

Premier Tower
Elenberg Fraser
Melbourne, Australia

Solomon R. Guggenheim Museum
Frank Lloyd Wright
New York, New York

Absolute World
MAD Architects
Mississauga, Ontario

Galaxy Soho
Zaha Hadid Architects
Beijing, China

The Gherkin
Norman Foster
London, UK

Ray and Maria Stata Center
Frank Gehry
Cambridge, MA

Previous Studies

Reference Work

1. Ko, Won Hee, Complex Geometry Facades in Building Energy Simulations and Standards, 2014 ASHRAE/IBPSA-USA Building Simulation Conference
   A. Review of energy codes and standards in regards to angular dependence of SHGC for glazing property requirements
   B. Comparison of several building energy simulation programs in modeling complex facades
      - A cube with vertical and tilted south facade
      - A 133' diameter 100% clear glass dome with varying frit pattern

Conclusion: Current energy simulation programs have limited or no capability to account for tilted glazing, which can lead to inaccurate SHG calculations

What do the codes/standards say?

Geometry-Related Terminology

Definitions from ASHRAE 90.1-2013

- Orientation: *"the direction an envelope faces, i.e., the direction of a vertical perpendicular to and pointing away from the surface outside of the element"*
- North-oriented: *"facing within 45 degrees of true north in the northern hemisphere (however, facing within 45 degrees of true south in the southern hemisphere)"*
- Fenestration area: *"total area of the fenestration measured using the rough opening and including the glazing, sash, and frame. For doors where the glazed vision area is less the 50% of the door area, the fenestration area is the glazing vision area. For all other doors, the fenestration area is the door area"*

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Industry Guidelines for Energy Model Geometry

- ASHRAE 90.1-2013, Table G3.1 5a states that "*Equivalent dimensions shall be assumed for each exterior component type as in the proposed design; i.e., the total gross area of the exterior walls shall be the same in the proposed and baseline building designs.*"
- ASHRAE 90.1-2013, Table G3.1 5, Exception 2 states that "*Exterior surfaces whose azimuth orientation and tilt differ by less than 45 degrees and are otherwise the same may be described as either a single surface or by using multipliers*"
- Best Practice (?): modeled floor area is within 10% of actual floor area

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Our Study

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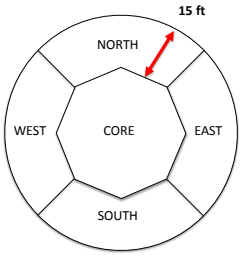
Modeling Methodology

- Circular floor plate as an idealized curved geometry
- 5 thermal blocks per floor:
  - A perimeter zone 15 ft from exterior facade for each cardinal direction
  - A single core zone, identical across all model iterations
- Modeled 10 floors



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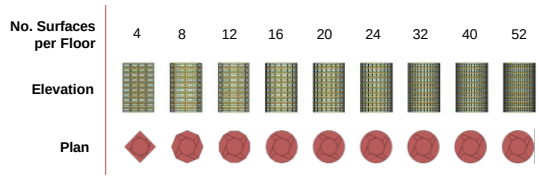
Model Iterations



- "Actual" building 4 ft. spacing between vertical mullions (52 surfaces per floor)
- Simplest model does not meet ASHRAE 90.1 requirements (8 surfaces per floor)

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Model Inputs

- Derived inputs from ASHRAE 90.1-2010, Appendix G requirements for building in Boston, MA (CZ5)
  - Reference standard for the current version of LEED (v4)
  - Available DesignBuilder templates
- Assumed generic office occupancy
- Aimed to isolate the effect of changing facade complexity
  - Two iterations to represent different design stages
  1. **Early Design**: EnergyPlus autosized HVAC equipment and internal gains as a function of area (i.e., lighting power density of 0.9 W/sf)
  2. **Late Design**: HVAC equipment capacities and internal gains fixed to match the "actual" building

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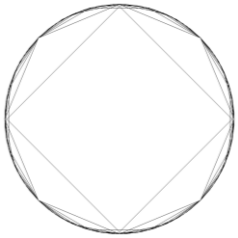
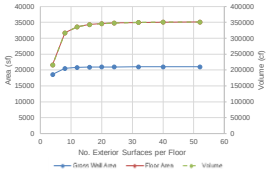
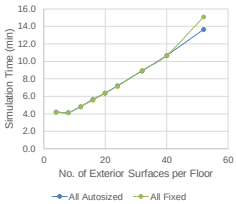
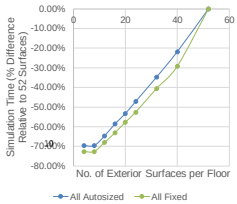
Geometry Variation





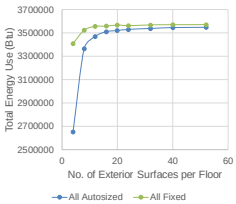
Results – Simulation Time

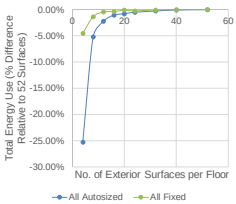




- 4 and 8 exterior surfaces per floor had similar run times
- Otherwise, increasing the number of exterior surfaces increase the simulation time

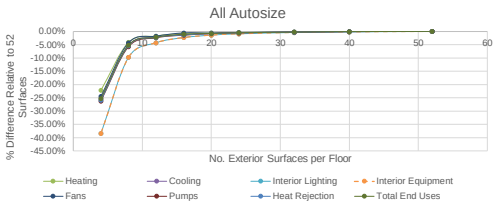
Results – Total Energy Use





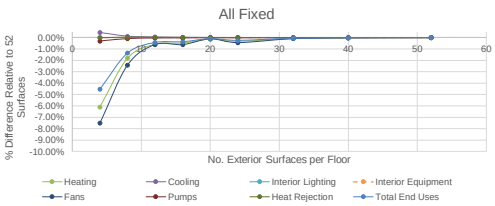
- Greatest gain in accuracy in between 4 and 8 exterior surfaces per floor
- For 24 exterior surfaces per floor or more, the % Difference is less than 1%
- Setting internal gains and HVAC equipment to match actual building improves accuracy of results, especially in less detailed models

Results – End Use Breakdown



- All end uses follow a similar trajectory – model accuracy increases with the number of exterior surfaces per floor

Results – End Use Breakdown



- Heating and fan end uses are most affected by model geometry and in turn effect the total end use
- Cooling and pumps end uses are not fixed values but are near constant with model geometry

Conclusions

- For compliance models, the baseline and proposed design have the same geometry.
- ASHRAE 90.1, Appendix G allows surfaces oriented within 45 degrees to be combined into a single surface.
  - ASHRAE 90.1 allowance to simplify surfaces within 45 degrees results in approx. 5% difference from “actual” total energy use (i.e., 8 surfaces to approximate 52 surfaces).
- Modeling results:
  - Simulation time increases with increasing model complexity.
  - Model outputs converge very quickly towards a single value with increasing complexity of geometry.
  - When HVAC equipment and internal gains are known, results are more accurate for models with simpler geometry.
  - When HVAC equipment and internal gains are autosized, outputs can vary by over 10%.

Recommendations

- Stick with ASHRAE recommendation for modeling surfaces within 45 degrees of each other as the same.
  - If mechanical systems and internal loads are not well defined, then model more definition in geometry.
  - If mechanical systems and internal loads are well defined, can get away with simplifying geometry.

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Questions?

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