Beyond the Shoebox: Thermal Zoning Approaches for Complex Building Shapes

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ABSTRACT

Current architectural trends as well as advanced building information modeling (BIM) software facilitate the design and construction of building forms that go far beyond the typical shoebox models commonly used for energy simulation. ASHRAE 90.1 Appendix G provides two-dimensional guidelines for how to model thermal zones in buildings where HVAC systems and zones have not yet been designed. What is the best way to zone unusual three-dimensional shapes that present issues beyond what is covered in the ASHRAE guidelines? This paper will examine this question and determine the impact on energy model outputs by studying 3 different unusually shaped buildings of 2 different building use types in 4 different climate zones. Several zoning approaches beyond the ASHRAE guidelines will be simulated and compared using DOE-2 simulation engine and TMY2 climate data.

INTRODUCTION

During the conceptual phase of building design, decisions such as basic form and orientation can have a significant effect on energy use, yet whole building energy analysis is rarely used to inform this design process. Typically, these studies have not been done because the tools and methods are too difficult and time consuming to use at early stages and models aren't built correctly for energy simulations and rapid design iteration. The 2008 Autodesk/AIA Green Index reports that architects believe that using the design process to reduce building energy consumption includes an increased reliance on design software. Leveraging existing software and making it easy to learn and use is important because nearly three-fourths of architects (72%) are concerned that clients are not willing to pay the added first costs of green designs (Autodesk/AIA 2008). McGraw/Hill reports that while fewer than 20% of firms are simulating energy performance, in two years 80% of firms see it as very important and want to simulate whole building energy use. (McGraw/Hill 2010). Underscoring the importance of early energy use studies, in September 2011, the USGBC introduced a new LEED credit encouraging teams to conduct analyses, including energy load reduction, so that they can understand key issues before design decisions are made (USGBC 2011).

In most cases, simple extruded representations of building geometry are used for energy modeling. Energy modeling programs, such as eQUEST, provide templates for zoning many different floor plan configurations; however, changing this configuration from floor to floor is difficult and time consuming. Advances in building modeling software, as well as design trends, are making more complex shaped buildings easier to design and build. Advances in energy modeling software are also making complex geometries easier to analyze for energy use. Recent advances in software provide

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functionality to automatically create an energy model from a conceptual model. (Smith, Bernhardt, and Jezyk 2011). Additionally, new algorithms can automatically divide more complex geometry into zones specific to the geometry at each floor based on ASHRAE 90.1 Appendix G modeling requirements of thermal blocks (Autodesk® Project Vasari 2011). Automatic zoning is important for conceptual stage energy modeling because design decisions about layout have not been made yet and the architects and engineers do not necessarily know yet how a building will be zoned. Providing a quick and automatic way to turn an architect's geometry into an appropriately zoned energy model without additional modeling is critical for doing early stage energy simulations. The goal of this paper is to demonstrate the importance of dividing a conceptual stage building into zones based on ASHRAE guidelines and to explore the sensitivity of choices required for automatic zoning beyond ASHRAE recommendations that were discovered in the development of these automated approaches.

METHODOLOGY

To investigate the various impacts of zoning approaches on energy model results, 3 different building geometries of 2 building use types were simulated using 4 different climate zones and building envelopes. The goal was to provide a representative range of building parameters for the study. ASHRAE guidelines for envelope settings and zoning configurations were used to simulate and compare the three geometrical options using a DOE-2 simulation engine and TMY2 climate data. Autodesk® Project Vasari software was used to generate the energy model geometry because of its capability to automatically divide complex geometries into energy models.

Building Geometries

Three different building geometries were chosen for this study, as shown in **Figure 1**. Each option has a different floor plan at each level due to the shape of the building. Option A is a deep plan configuration with an angled front face. Option B is a tall narrow building with a bowed front and Option C is a long thin building with a large sloped roof.

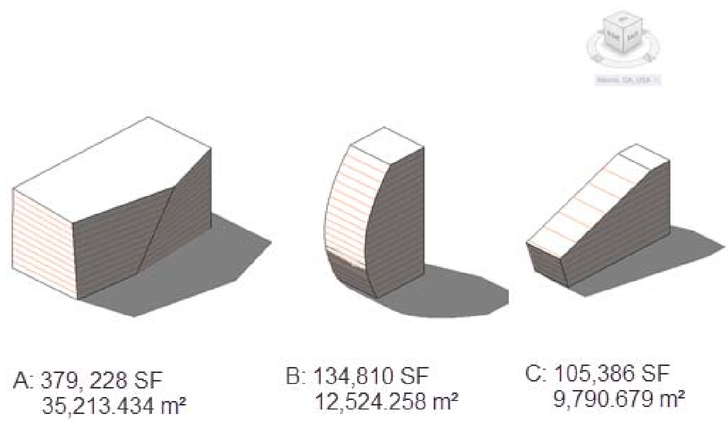


Figure 1 *Building geometries and their associated square footages.*

Building Types

Two different building types were selected for the simulations. Each of the three geometries was simulated as an office and as a healthcare facility. Assumptions for these building types are based on ASHRAE guidelines. The biggest difference in these 2 building types is the people density with the Healthcare facility having a much greater density – 10 people/100sq M (1076.391 ft²) vs 3.5 people/100 sq. M. (1076.391 ft²) for the office. The Healthcare facility is also operated for more hours than the office building.

Climates

Four different climates were chosen to represent a variety of different conditions as shown in Table 1.

Table 1 Climates

City	Region	Zone	HVAC
Minneapolis	Northern	6A Cold/Humid	Mostly Heating
Baltimore	North/Central	4A Mixed/Humid	Heating & Cooling
Atlanta	South/Central	3A Mixed/Humid	Heating & Cooling
Phoenix	South	2B Hot/Dry	Mostly Cooling

Weather data

TMY2 (Typical Meteorological Year) data was used for weather data to represent a range of weather conditions that was also consistent with long term averages for the location. Studies have shown that TMY2 data is appropriate for this kind of study (Crawley and Huang 1997).

Building Envelope

Different envelopes (Table 2 and Table 3) were specified for each location, based on ASHRAE 90.1 2007 Table 5.5-1-6 Building Envelope Requirements for Climate Zones, and the choices offered by Project Vasari. Minneapolis and Baltimore had the same settings as did Atlanta and Phoenix. All climate zones used the same glazing values.

Table 2 Building Envelop Settings Per Location

Location	Surface	R-Value (ft²-hr °F/Btu)	Unit Density (lbm/ ft²)	Heat Capacity (Btu/(ft²•°F)
Minneapolis	Exterior Wall	17	21	4
	Roof	22	10	3
	Floor	29	4	1
	Slab on Grade	16	123	25
Baltimore	Exterior Wall	17	21	4
	Roof	22	10	3
	Floor	29	4	1
	Slab on Grade	16	123	25
Atlanta	Exterior Wall	17	21	4
	Roof	22	10	3
	Floor	21	4	1
	Slab on Grade	11	123	25
Phoenix	Exterior Wall	17	21	4
	Roof	22	10	3
	Floor	21	4	1
	Slab on Grade	11	123	25

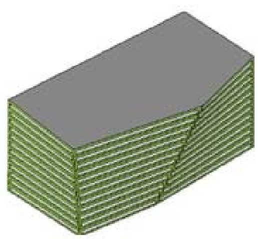
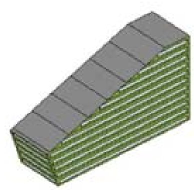
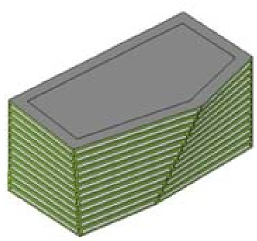
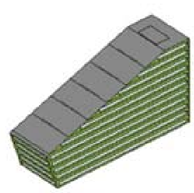
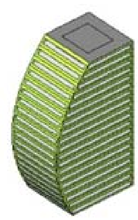
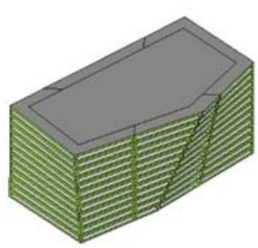
Table 3 Glazing Settings

Location	Surface	U-Value $Btu/(ft^2 \cdot {}^\circ F \cdot h)$	Solar Heat Gain Coefficient	Visible Transmittance
All	Glazing	0.56	0.69	0.78

Zoning Configurations

Eight zoning configurations were chosen for testing (Table 4). The first three configurations purposely do not follow ASHRAE recommendations in order to illustrate the importance of the zoning guidelines. Zoning configuration 1 is simply one zone per floor. Zoning configuration 2 is one zone per floor with a 15’ deep perimeter zone, but no further zone divisions. Zoning configuration 3 takes the centroid of the geometry and creates a cut based on 4 cardinal directions after dividing the building into floors and a 15' offset perimeter zone. This is a very simple way to algorithmically cut many different shapes, but can create zones with multiple exposures. Zoning configuration 4 and 5 explore different perimeter zone depths of 10’ and 20’ instead of the ASHRAE recommended 15’. Zoning configuration 6 explores questions that arise with geometries that are not extruded; for example, walls that splay out or a large sloped roof as in Geometry B. This zoning configuration offsets the perimeter depth at the floor, rather than half way between levels which is the Project Vasari default behavior. Zoning configuration 7 simulates examples with no specified maximum zone length. ASHRAE does not specify a maximum zone length; however, common practice is to separate zones that are greater than 70’ and this is the Vasari default. The final configuration is the comparison case with the ASHRAE standard 15’ perimeter depth and Vasari default setting to cut the plan at 5’ vertically from the floor and impose a 70’ maximum zone length.

Table 4 Zoning Configurations

Zoning Configuration	Geometry A	Geometry B	Geometry C
1. One zone per floor			
2. 15' perimeter depth that are not divided into further zones			
3. Cardinal direction zoning			

4. 10’ perimeter depth

5. 20’ perimeter depth

6. Level cut at floor instead of mid-way between levels

7. 15' perimeter depth, no maximum zone length

8. 15' perimeter depth, perimeter divided per ASHRAE 90.1. Plan cut at 5’ above floor with a maximum 70’ zone length. This is the comparison case.

Simulation Engine

Simulations were run using Autodesk® Green Building Studio® software and DOE-2.2-44e4.

RESULTS

Simulation results are shown in Figure 2. Percentage difference of total fuel and electric use are compared to zoning configuration 8. Fuel and electric use values were used because they are commonly understood values, reflect where the differences mattered most, and remove any further complications involving utility tariffs. Percentage differences of more than 3% are considered significant because changes of +/-2% can mean an entire LEED energy point (USGBC 2009).

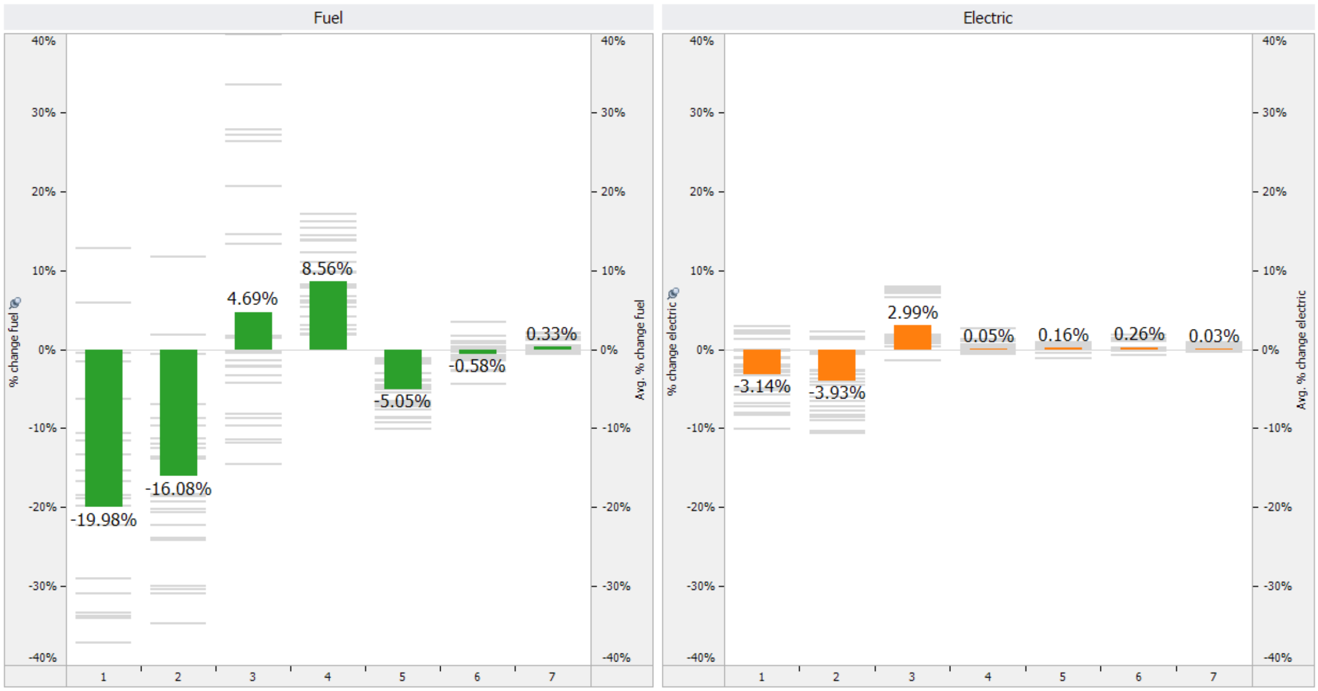


Figure 2 *Results shown in percentage difference from the base case (zoning configuration 8) for fuel and electric use over all climates, geometries, and building types per zoning configuration. Solid bars show the average percentage difference and background grey lines plot each run.*

Zoning configurations 1, 2, and 3, which do not follow ASHRAE guidelines, display up to 40% difference from the comparison case. Configuration 4 (10' divided perimeter zone) displays a consistent overestimation of fuel use averaging over 8%. Configuration 5 (20' divided perimeter zone) shows a consistent underestimation of fuel use averaging -5%. Results for electric use average differences in both cases are negligible. The differences for configuration 6, level cut at floor instead of mid-way between levels, show negligible average differences for electric use, however, in these cases, the results could still differ by as much as 3% to -4.5% for fuel use. The last case, configuration 7, which tested no maximum zone length, showed a negligible average difference in both fuel and electric use.

Looking in depth at percentage difference in fuel and electric use per building geometry (Figure 3), we can see that the results from the different configurations are consistently over or under estimated use, except for Geometry A configuration 3 (Table 4 Zoning Configurations), where the deep plan of this geometry option reacts strongly to cardinal direction zoning due to zones wrapping around 3 orientations, and overestimates fuel use by 25% and electric use by 7%. Configuration 6 (level cut at floor instead of mid-way between levels) shows negligible differences, except in the angled geometry case C where the differences range from -5% to 3%.

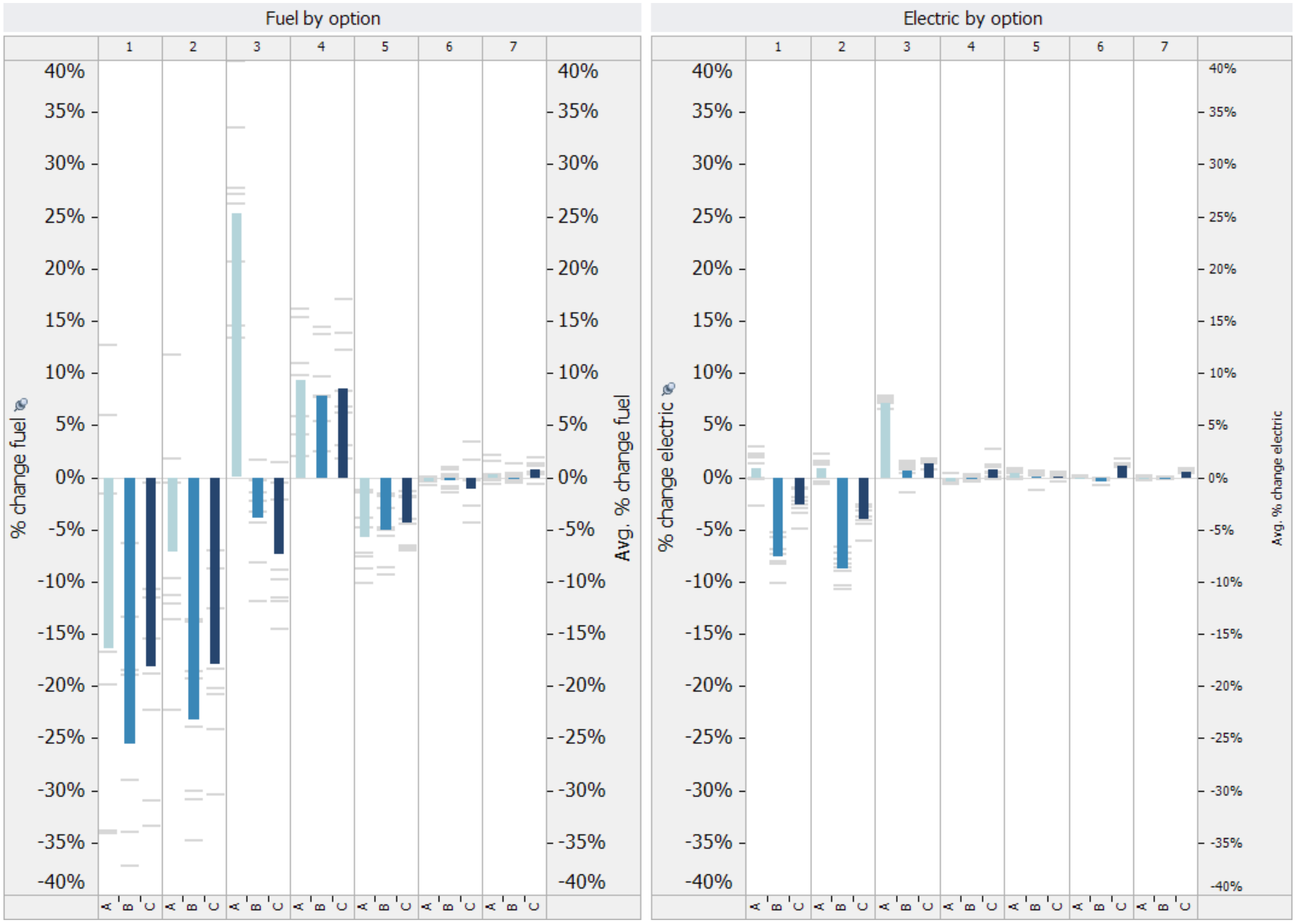


Figure 3 *Percentage difference in fuel and electric use per zoning configuration and geometry option. Solid bars show average percentage differences as compared to configuration 8 and gray background lines plot the percentage differences of each run.*

CONCLUSION

The results demonstrate that zoning configurations 1-3, which do not follow ASHRAE guidelines, can significantly affect energy simulations and should not be used because they primarily underestimate energy use which is problematic for early studies. Overestimation is arguably preferred so that designers won't be encouraged to follow designs that use more energy. Configuration 3 is especially problematic in that it can both under and overestimate energy use and due to the fact that in deep plan buildings zones can actually wrap around multiple orientations. Sensitivities beyond ASHRAE recommendations, as seen in results from configurations 4-7, are also significant because changes in 2% can mean an entire LEED energy point. Configuration 4 (10' divided perimeter zones) consistently overestimates use by an average of over 8% and configuration 5 (20' divided perimeter zones) underestimates use by an average of -5%. Comparisons of these configurations suggest that perhaps a better default for perimeter offset would be closer to 16'. Changing the location of the plan cut where the perimeter offset is measured (configuration 6) are negligible in this study, but can make a significant difference especially in cases like Geometry C where results range from -5% to 3% due to the significant sloping geometry.

This suggests that perhaps the level of the plan cut should be a user controllable option. For configuration 7, no maximum zone length, all runs are within a 2% difference suggesting that this setting may be unnecessarily creating more zones and complexity than required. This study presents a limited set of options and climates due to feasibility of conducting the simulation runs. Future studies could extend the selected options to further validate these conclusions.

Overall, these results demonstrate the importance of reasonable zoning in conceptual models. Using software to automatically cut geometric forms with a different floor plan at each level into valid energy models can be a huge benefit for studying form and orientation at the earliest stage of design when changes of this nature can be made and will have a big effect on energy use. Automatic zoning algorithms that can be trusted to return reliable early stage energy simulation results can enable rapid design iteration, which allows for more studies and options to be considered and intelligently analyzed.

ACKNOWLEDGMENTS

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