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under Contract DE-AC05-76RL01830

QuickSim Analysis Report

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October 2010

Pacific Northwest
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Executive Summary

In software tools such as COM*check*, use of the EnergyPlus simulation engine for performance-based code compliance raises a concern about simulation runtime, which impacts the dynamic feedback of compliance results to the user. EnergyPlus annual simulations for proposed and code base line building models, and the mechanical equipment sizing runs together increase the annual simulation runtime beyond unacceptable duration, for example, to 5 minutes for a typical small commercial building. This report presents a study undertaken to compare the results of a shortened simulation time period, using 4 weeks of weather data to a simulation using a full 52 weeks of data. Three representative building types and three climate zones were used for determining the validity of using shortened simulation run period. Further sensitivity analysis and run time comparisons were made to evaluate the robustness and runtime savings of using this approach. The results of this analysis show that the shortened simulation run period provides compliance index calculations within 1% of those predicted using annual simulation results, and typically saves about 75% of simulation runtime.

Acronyms and Abbreviations

PNNL	Pacific Northwest National Laboratory
EUI	Energy use intensity
LPD	Lighting power density
ASHRAE	American Society of Heating, Refrigeration and Air-Conditioning Engineers
SHGC	Solar heat gain coefficient

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1.0 Introduction

EnergyPlus is a whole building energy simulation program that engineers, architects, and researchers use to model energy use in buildings. The Building Energy Codes Program is currently linking COM*check* with EnergyPlus simulation engine to support performance-based energy code compliance using ASHRAE 90.1-2007 Section 11: Energy Cost Budget Method. One of the challenges software developers face when employing any whole building simulation software is the detailed input and simulation runtime that impact the dynamic feedback often expected by users.

To determine energy code compliance, a budget building configuration and a proposed design configuration must be simulated. It was determined that to run these two simulations using typical commercial building configurations and on a full year simulation period, EnergyPlus required a runtime of 5 minutes on average. Energy code compliance software, such as COM*check*, attempt to report the impact of incremental changes to a building configuration immediately. A 5 minute runtime clearly compromises that capability.

To address the runtime issue and user feedback problem, it was proposed that simulation runs could be initiated by the user instead of being launched immediately with each configuration change. Furthermore, it was recognized that shorter runtimes might be achievable if the simulation periods could be shortened. Assuming the shortened period simulation results proved to be good approximations of the full period simulation results, the user could have a more productive experience in designing and defining the building configuration that achieves energy code compliance. After the building configuration was fully defined, the user would run a full simulation to determine the final compliance result.

This report describes the methodology, sensitivity analysis, and results of evaluating whether compliance results based on shortened simulation periods are reasonable approximations of full year simulation results.

1.1 Objective

The objective of this study is to develop a methodology (here after called “QuickSim”) for reducing the EnergyPlus simulation runtime when used specifically for energy code compliance determinations and to determine if results based on QuickSim are reasonable and reliable approximations of results that are based on full year simulations. The following evaluation criteria were developed in support of this objective:

a. Trade-off Analysis: In energy code compliance determinations, the performance of assembly types can be balanced against one another as long as the overall proposed design building energy metric is less or equal to the budget building energy metric. For this effort, six typical trade-off options are chosen for testing QuickSim.
b. Sensitivity Analysis: Sensitivity of QuickSim to incremental changes in individual building components is evaluated in this test.

c. Runtime Comparison: The runtimes for full year and QuickSim partial year simulations are to be collected and compared to determine if reliable and consistent runtime reductions are obtainable with the methodology.

1.2 Scope

The scope of this study is limited to a set of building types and climate locations that are deemed representative of a cross-section of building types and climate zones. QuickSim will only be applied to predicting the performance of the proposed building relative to a baseline building. The methodology will not give accurate results for predicting the annual energy use of a building for which an annual simulation should be performed.

2.0 Modeling Assumptions

The following modeling parameters and assumptions were applicable to this research:

1. EnergyPlus version 4.0 (released in October 2009) is used for the performance simulation software.

2. A compliance index is used as a measure of the proposed building's performance relative to a baseline building. The compliance index is simply the difference in the energy use intensity (EUI) of the baseline building and the proposed building divided by the energy use intensity of the baseline building. It is typically expressed as a percentage.

$$\text{Compliance Index} = \frac{EUI_{base} - EUI_{proposed}}{EUI_{base}} \qquad (1)$$

where, EUI is the energy use intensity in kBtu/ft^2.

3. A QuickSim compliance index is calculated using equation (1), by substituting the EUIs of the base and proposed building from the annual run with the EUIs from the QuickSim run.

4. When evaluating the QuickSim methodology, the QuickSim compliance index is compared to the annual compliance index. The absolute difference in the two compliance indices, expressed as percentages, is used to evaluate the QuickSim method. The delta or variation between the compliance indices is considered acceptable if it is lower than 1.0%.

5. For all the tests in the study, the baseline prototype building is assumed to comply minimally with ASHRAE Standard 90.1-2004.

6. Tests to evaluate QuickSim are performed on three arbitrarily chosen building prototypes in three representative climate locations. It is assumed that if QuickSim provides a reasonable and reliable approximation of the annual simulation results for the above cases, it can be applied to other building prototypes and climate locations also.

3.0 Methodology

It is impossible to capture the full variation of conditions in a year by selecting just a few days or weeks. However, the goal is consistency in passing and failing of a baseline and proposed simulation. A subset of conditions that mimic the average or typical conditions of an annual run may be adequate. The subset must be selected such that it adds little to no preprocessing time in setting up such a simulation run. It is also important that the subset run periods be constant across building types and climate locations.

There are several methods to select the subset of time that would best represent the annual weather conditions. The easiest method would be to select a subset of time for each season in a year. For example, weeks 4, 17, 30, 43 would represent spring, summer, fall and winter. It is assumed that 1 week in each of these seasons would be enough to capture the typical variations. Another method would be to use some predefined categorization for each weather file. For example, the STAT file for each EPW weather file includes typical summer, winter, autumn and spring weeks, and these could be used for the subset. Finally, processing and selecting subsets of time for each individual weather file was another method considered, but it was discounted because of the volume of work required in evaluating the full spectrum of files.

For no other reason than the simplicity of the implementation, the static 4-week strategy was chosen for this research. Weeks 4, 17, 30 and 43 are chosen as representative weeks for the four seasons in a year. These particular weeks have no special significance to each season they are associated with, but consistently span 13 weeks. To evaluate the sensitivity of the selected weeks, alternative subsets of weeks will be considered, again using 13-week increments, to cover all four seasons.

3.1 Parametric Simulation Structure

All energy simulations were completed within a PNNL Linux energy simulation infrastructure, which manages inputs and outputs of the EnergyPlus simulations. This infrastructure includes creating EnergyPlus input files by a PNNL-developed program known as GPARM, submitting input files to a computing cluster with 80 central processing units (CPUs) for batch simulation, and extracting energy end-use results.

3.2 Building Types

A representative cross section of building types was selected for the analysis. These building types included Medium Office, Retail Strip Mall and Primary School. These prototype building models are based on DOE's commercial reference building models. They have been modified to comply minimally with Standard 90.1-2004. The Small Office prototype was used initially as a proof of concept for the QuickSim method. Table 1 shows the building description for these three prototypes.

Table 1: Building description for Medium Office, Retail Strip Mall and Primary School

	Medium Office	Retail Strip Mall	Primary School
GENERAL			
Gross Floor Area	53,600 ft²	22,500 ft²	73,960 ft²
Building Shape	Rectangle	Rectangle	Classroom Wings + Core
Aspect Ratio	1.5 (164 ft x 109 ft)	4.0 (300 ft x 75 ft)	270 ft x 340 ft
Number of Floors	3	1	1
Window-to-Wall Ratio	33%	10.5%	35%
Floor Height	13 ft	17 ft	13 ft
Floor-to-Ceiling Height	9 ft	17 ft	13 ft
Exterior Wall	Steel-framed wall	Steel-framed wall	Steel-framed Wall
Roof	Insulation entirely above deck, Built Up Roof	Insulation entirely above deck, Built Up Roof	Insulation entirely above deck, Built Up Roof
Floor	8” Slab-on-grade	6” Slab-on-grade	6” Slab-on-grade
INTERIOR LOADS			
Occupancy			
Number of People	5 people / 1000 ft²	8 people / 1000 ft²	19 people / 1000 ft² (peak)
Lighting			
Average Power Density	1.0 W/ft²	1.65 W/ft²	1.19 W/ft²
Plug Load			
Average Power Density	0.75 W/ft²	0.4 W/ft²	9.80 W/ft²
HVAC			
Heating Type	Gas furnace	Gas furnace	Gas Furnace Gas Boiler
Cooling Type	Packaged DX Unit	Packaged DX Unit	Packaged AC, Packaged VAV
Fan Control	Variable air volume	Constant Air Volume	Constant Air Volume, Variable Air Volume
Distribution/Terminal Units	VAV terminal box with electric reheating coil	CAV	CAV, VAV with terminal box with hot water reheat
Cooling T-stat	75°F (80°F setback)	75°F (85°F setback)	75°F (80°F setback)
Heating T-stat	70°F (60°F setback)	70°F (60°F setback)	70°F (60°F setback)
SERVICE WATER HEATER			
Water Heater Type	Electric water heater	Natural Gas water heater	Natural Gas water heater
Tank Capacity	260 gal	6 gal	264 gal
Supply Temperature	120°F	120°F	120°F

3.3 Climate Locations

As with building types, a cross section of representative climate zones were selected for the QuickSim analysis. The selected climate zones were Houston, Chicago and Duluth.

3.4 Test Cases

As stated in the introductory sections of this report, three types of tests were performed on the QuickSim sample set to determine the feasibility of reduced runtimes using EnergyPlus.

3.4.1 Trade-off Comparison

Energy code compliance using the performance alternative enables trading-off between building components and equipment of the proposed building to meet compliance requirements. For QuickSim to be successful, it must reliably determine trade-off possibilities on the proposed building. The primary trade-off opportunities considered for this analysis are:

- Wall insulation
- Window type
- Equipment efficiency
- Lighting power density.

Assuming that the trade-offs are made between just two of those options, the list of trade-offs would be:

1. Wall and roof insulation to equipment efficiency
2. Wall and roof insulation to window type
3. Wall and roof insulation to lighting power
4. Window type to equipment efficiency
5. Window type to lighting power
6. Equipment efficiency to lighting power.

Initial trade-off opportunities were evaluated at the 10% level of change. More specifically, for each selected climate location and building type, the level of one component in each pair in the list above is reduced by approximately 10%, while the other component's level is increased by 10%. This gives rise to six trade-off cases. These trade-off cases are used to test the QuickSim method against the annual simulation results.

Because of the limitations in the parametric simulation structure, it may not be possible to simulate an increase or decrease of exactly 10% in some of the components. For example, the equipment efficiency can only be switched between 90.1-2004, 90.1-2007 and 90.1-2010 levels. In such instances, it is assumed that the next available level will provide the minimum 10% difference.

The trade-off cases are described in detail below.

1. Wall and roof insulation to equipment efficiency: The wall and roof insulation is reduced by 10%, while the equipment efficiency is increased from the 2004 standard to the 2010 standard.

2. Wall and roof insulation to window type: The wall and roof insulation is reduced by 10%, while the windows are upgraded to the 2010 standard.

3. Wall and roof insulation to lighting power density: The wall and roof insulation is reduced by 10%, while the lighting power density (LPD) is upgraded to the 2010 standard.

4. Window type to equipment efficiency: Window types with lower U and SHGC are chosen, while equipment efficiency is increased to the 2010 standard.

5. Window type to lighting power density: Windows with lower U and SHGC are chosen, while LPD is upgraded to the 2010 standard.

6. Equipment efficiency to lighting power: Equipment efficiency was increased to the 2010 standard, while the LPD was increased by 10%.

These six trade-off cases were run for the three selected prototypes in the three climate locations, for annual and QuickSim run periods, giving rise to 42 cases per prototype and 126 cases in total.

3.4.2 Sensitivity Analysis

A sensitivity analysis is performed on the QuickSim method to analyze its response to different magnitudes of change in the trade-off components. The trade-off cases created in the previous test are used again for the sensitivity analysis, but the changes made to the components are more gradual. For each trade-off case, six performance levels are created by assigning one of the components in the pair a fixed value, and gradually increasing or decreasing the other component. These performance levels are described in greater detail below.

1. Wall and roof insulation to equipment efficiency: To create the six performance levels, the wall and roof insulation level is varied while fixing the equipment efficiency at the 2010 standard. The wall and roof insulation levels are changed between -30%, -20%, -10%, +10%, +20%, +30%, compared to the 2004 baseline levels.

2. Wall and roof insulation to window type: Again, to obtain six performance levels, the window type is fixed at the 2004 standard. The wall and roof insulation level is then varied between -30%, -20%, -10%, +10%, +20%, +30%, over the 2004 baseline.

3. Wall and roof insulation to lighting power: The wall and roof insulation levels are varied between -30%, -20%, -10%, +10%, +20%, +30%, over the 2004 baseline while keeping the LPD at the 2004 level. This gives six performance levels.

4. Window type to equipment efficiency: This is a special case, where both components must be varied to obtain six performance levels. Three window types and three equipment efficiencies (2004, 2007, 2010) were chosen. A combination of the two sets of values for each component gives six levels.

5. Window type to lighting power: In this case, the window type was held constant at the 2004 standard, and the LPD was varied between -30%, -20%, -10%, +10%, +20%, +30%, over the 2004 standard. This gives the six performance levels.

6. Equipment efficiency to lighting power: Equipment efficiency was raised to the 2010 standard to distinguish these set of simulation runs from other cases of the sensitivity analysis.The lighting power density (LPD) was varied between -30%, -20%, -10%, +10%, +20%, +30%, over the 2004 standard. Thus, six performance levels were obtained.

3.4.3 Runtime Comparison

Measuring and evaluating the impact of QuickSim on simulation runtimes is only meaningful if the simulations are performed on a computing platform most likely to be used for energy code compliance. The computing platform chosen for this study was the Windows XP operating system running on a standard desktop workstation. The system configuration is described in Section 4.3. The total number of unique simulation runs created under the trade-off comparison test (Section 3.4.1) is 126, each of which will be run on this type of system.

4.0 Analysis

In Section 4.1, results from the trade-off comparison are presented. Section 4.2 shows results from the sensitivity analysis, and Section 4.3 documents the results of the run time comparison. Section 4.4 discusses the possibility of using a different subset of weeks from the one chosen for QuickSim. Lastly, a brief analysis performed on the alternate subset is presented.

4.1 Trade-off Comparison Analysis

The trade-off comparison uses different levels of wall and roof insulation, LPD, window type and equipment efficiency. These levels are varied to create the trade-off cases and also the cases in the sensitivity analysis.

Table 2: Trade-off component levels for prototype buildings

Building	Location	Component	Component Level						
			-30%	-20%	-10%	0%	10%	20%	30%
Retail Strip Mall	Houston	Wall R-value (h-ft^2-F/Btu)	5.6	6.5	7.3	8.1	8.9	9.7	10.5
		Roof R-value (h-ft^2-F/Btu)	11.1	12.7	14.3	15.9	17.5	19.0	20.6
		LPD (W/ft^2)*	1.60	1.82	2.05	2.28	2.51	2.74	2.96
	Chicago	Wall R-value (h-ft^2-F/Btu)	10.9	12.5	14.1	15.6	17.2	18.8	20.3
		Roof R-value (h-ft^2-F/Btu)	11.1	12.7	14.3	15.9	17.5	19.0	20.6
		LPD (W/ft^2)*	1.60	1.82	2.05	2.28	2.51	2.74	2.96
	Duluth	Wall R-value (h-ft^2-F/Btu)	10.9	12.5	14.1	15.6	17.2	18.8	20.3
		Roof R-value (h-ft^2-F/Btu)	11.1	12.7	14.3	15.9	17.5	19.0	20.6
		LPD (W/ft^2)*	1.60	1.82	2.05	2.28	2.51	2.74	2.96
Medium Office	Houston	Wall R-value (h-ft^2-F/Btu)	5.6	6.5	7.3	8.1	8.9	9.7	10.5
		Roof R-value (h-ft^2-F/Btu)	11.1	12.7	14.3	15.9	17.5	19.0	20.6
		LPD (W/ft^2)	0.70	0.80	0.90	1.00	1.10	1.20	1.30
	Chicago	Wall R-value (h-ft^2-F/Btu)	8.3	9.5	10.7	11.9	13.1	14.3	15.5
		Roof R-value (h-ft^2-F/Btu)	11.1	12.7	14.3	15.9	17.5	19.0	20.6
		LPD (W/ft^2)	0.70	0.80	0.90	1.00	1.10	1.20	1.30
	Duluth	Wall R-value (h-ft^2-F/Btu)	10.9	12.5	14.1	15.6	17.2	18.8	20.3
		Roof R-value (h-ft^2-F/Btu)	11.1	12.7	14.3	15.9	17.5	19.0	20.6
		LPD (W/ft^2)	0.70	0.80	0.90	1.00	1.10	1.20	1.30
Primary School	Houston	Wall R-value (h-ft^2-F/Btu)	5.6	6.5	7.3	8.1	8.9	9.7	10.5
		Roof R-value (h-ft^2-F/Btu)	11.1	12.7	14.3	15.9	17.5	19.0	20.6
		LPD (W/ft^2)*	0.98	1.12	1.26	1.40	1.54	1.68	1.82
	Chicago	Wall R-value (h-ft^2-F/Btu)	8.3	9.5	10.7	11.9	13.1	14.3	15.5
		Roof R-value (h-ft^2-F/Btu)	11.1	12.7	14.3	15.9	17.5	19.0	20.6
		LPD (W/ft^2)*	0.98	1.12	1.26	1.40	1.54	1.68	1.82
	Duluth	Wall R-value (h-ft^2-F/Btu)	10.9	12.5	14.1	15.6	17.2	18.8	20.3
		Roof R-value (h-ft^2-F/Btu)	11.1	12.7	14.3	15.9	17.5	19.0	20.6
		LPD (W/ft^2)*	0.98	1.12	1.26	1.40	1.54	1.68	1.82

Table 2 shows the actual R-values (h-ft^2-F/Btu) and LPDs (W/ft^2) that are used in the test cases for the three prototypes in Houston, Chicago and Duluth. The 0% level corresponds to the 90.1-2004 baseline building. The equipment efficiency and window type can be varied only between the baseline, 90.1-2007 and 90.1-2010 standards. The reader is directed to these standards for information on these levels.

4.1.1 Retail Strip Mall Building Trade-off Comparison

Table 3 shows the building energy use intensity (EUI) and compliance indices for the 42 simulation cases for the Retail Strip Mall prototype. The first column provides a brief description of the trade-off case. The EUI for the annual and QuickSim run are shown. The EUI for the QuickSim run is small compared to the annual EUI because the simulation is run only for 4-weeks instead of the entire year. The compliance index (Section 2) provides a measure of comparison between the QuickSim run and the annual run. The last column presents the absolute difference between the QuickSim and annual compliance indices.

Table 3: Comparison of QuickSim and annual compliance indices for the Retail Strip Mall building

Case/Trade-off Description	Location	EUI		Compliance Index		% Delta
		Annual	QuickSim	Annual	QuickSim	
Baseline: Standard 90.1 2004						
Standard 90.1-2004 minimally code compliant building	Houston	70.49	5.67	-	-	-
	Chicago	100.51	7.84	-	-	-
	Duluth	134.4	11.76	-	-	-
1. Wall and Roof Insulation to Equipment Efficiency						
Wall and roof insulation reduced by 10% from baseline and equipment efficiency increased to the 90.1-2010 standard.	Houston	69.68	5.6	1.1%	1.2%	**-0.1%**
	Chicago	101.4	7.89	-0.9%	-0.6%	**-0.2%**
	Duluth	136.66	11.94	-1.7%	-1.5%	**-0.2%**
2. Wall and Roof Insulation to Window Type						
Wall and roof insulation reduced by 10% from baseline and windows upgraded to the 90.1-2010 standard.	Houston	71.05	5.71	-0.8%	-0.7%	**-0.1%**
	Chicago	102.11	7.94	-1.6%	-1.3%	**-0.3%**
	Duluth	136.62	11.96	-1.7%	-1.7%	**0.0%**
3. Wall and Roof Insulation to LPD						
Wall and roof insulation reduced by 10% from baseline and lighting power density upgraded to the 90.1-2010 standard.	Houston	67	5.4	5.0%	4.8%	**0.2%**
	Chicago	99.82	7.76	0.7%	1.0%	**-0.3%**
	Duluth	135.4	11.84	-0.7%	-0.7%	**-0.1%**
4. Window type to Equipment Efficiency						
Window U and SHGC increased by 10% from baseline and equipment efficiency increased to the 90.1-2010 standard.	Houston	69.11	5.54	2.0%	2.3%	**-0.3%**
	Chicago	99.85	7.77	0.7%	0.9%	**-0.2%**
	Duluth	134.14	11.75	0.2%	0.1%	**0.1%**
5. Window type to LPD						
Window U and SHGC increased by 10% from baseline and lighting power density upgraded to the 90.1-2010 standard.	Houston	66.41	5.35	5.8%	5.6%	**0.1%**
	Chicago	98.24	7.64	2.3%	2.6%	**-0.3%**
	Duluth	132.86	11.64	1.1%	1.0%	**0.1%**
6. LPD to Equipment Efficiency						
Lighting power density increased by 10% from baseline and equipment efficiency increased to the 90.1-2010 standard.	Houston	71.64	5.75	-1.6%	-1.4%	**-0.2%**
	Chicago	101.36	7.91	-0.8%	-0.9%	**0.0%**
	Duluth	135.1	11.82	-0.5%	-0.5%	**0.0%**

The maximum variation of the QuickSim compliance index from the annual compliance index is 0.3% and occurs in Houston for trade-off case 4 (window type to equipment efficiency). The minimum variation is 0%, while the average variation is 0.2%. A compliance index variation of less than 1.0% is considered to be acceptable, and all the simulation runs for the Retail Strip Mall building are able to achieve this target.

4.1.2 Medium Office Building Trade-off Comparison

Table 4 shows building EUI and compliance indices for the 42 simulation cases of the Medium Office building. The maximum variation of the QuickSim compliance index from the annual compliance index is 0.4% and occurs in Houston for trade-off case 1 (wall and roof insulation to equipment efficiency). The minimum variation is 0%, while the average variation is 0.2%. A compliance index variation of less than 1.0% is considered acceptable, and all the simulation runs for the Medium Office building are able to achieve this target.

Table 4: Comparison of QuickSim and annual compliance indices for the Medium Office building

Case/Trade-off Description	Location	EUI		Compliance Index		% Delta
		Annual	QuickSim	Annual	QuickSim	
Baseline: Standard 90.1 2004						
Standard 90.1-2004 minimally code compliant building	Houston	46.84	3.88	-	-	-
	Chicago	49.71	4.13	-	-	-
	Duluth	55.76	4.96	-	-	-
1. Wall and Roof Insulation to Equipment Efficiency						
Wall and roof insulation reduced by 10% from baseline and equipment efficiency increased to the 90.1-2010 standard.	Houston	45.35	3.74	3.2%	3.6%	**-0.4%**
	Chicago	49.18	4.07	1.1%	1.5%	**-0.4%**
	Duluth	55.97	4.98	-0.4%	-0.4%	**0.0%**
2. Wall and Roof Insulation to Window Type						
Wall and roof insulation reduced by 10% from baseline and windows upgraded to the 90.1-2010 standard.	Houston	46.74	3.87	0.2%	0.3%	**0.0%**
	Chicago	49.39	4.11	0.6%	0.5%	**0.2%**
	Duluth	55.1	4.92	1.2%	0.8%	**0.4%**
3. Wall and Roof Insulation to LPD						
Wall and roof insulation reduced by 10% from baseline and lighting power density upgraded to the 90.1-2010 standard.	Houston	46.19	3.83	1.4%	1.3%	**0.1%**
	Chicago	49.46	4.1	0.5%	0.7%	**-0.2%**
	Duluth	55.72	4.96	0.1%	0.0%	**0.1%**
4. Window type to Equipment Efficiency						
Window U and SHGC increased by 10% from baseline and equipment efficiency increased to the 90.1-2010 standard.	Houston	45.04	3.73	3.8%	3.9%	**0.0%**
	Chicago	49.02	4.07	1.4%	1.5%	**-0.1%**
	Duluth	55.46	4.93	0.5%	0.6%	**-0.1%**
5. Window type to LPD						
Window U and SHGC increased by 10% from baseline and lighting power density upgraded to the 90.1-2010 standard.	Houston	45.89	3.81	2.0%	1.8%	**0.2%**
	Chicago	48.88	4.07	1.7%	1.5%	**0.2%**
	Duluth	55.21	4.91	1.0%	1.0%	**0.0%**
6. LPD to Equipment Efficiency						
Lighting power density increased by 10% from baseline and equipment efficiency increased to the 90.1-2010 standard.	Houston	46.26	3.82	1.2%	1.5%	**-0.3%**
	Chicago	49.63	4.11	0.2%	0.5%	**-0.3%**
	Duluth	56.19	5.00	-0.8%	-0.8%	**0.0%**

4.1.3 Primary School Building Trade-off Comparison

Table 5 shows building EUI and compliance indices for the 42 simulation cases of the Primary School building type. The maximum variation of the QuickSim compliance index from the annual compliance index is 1.4% and occurs in Duluth for trade-off case 4 (window type to equipment efficiency). The minimum variation is 0.1%, while the average variation is 0.4%. The maximum variation of the QuickSim method rises twice above the 1.0% threshold for acceptable variation out of 42 simulation runs. All the other cases fall under maximum acceptable compliance index variation. The compliance index delta does go over 1.0% for two cases, but it exceeds the threshold by only 0.4% which is small. Therefore, these data points can be considered aberrations and ignored.

Table 5: Comparison of QuickSim and annual compliance indices for the Primary School building

Case/Trade-off Description	Location	EUI		Compliance Index		% Delta
		Annual	QuickSim	Annual	QuickSim	
Baseline: Standard 90.1 2004						
Standard 90.1-2004 minimally code compliant building	Houston	68.00	5.56	-	-	-
	Chicago	89.39	7.04	-	-	-
	Duluth	121.45	10.76	-	-	-
1. Wall and Roof Insulation to Equipment Efficiency						
Wall and roof insulation reduced by 10% from baseline and equipment efficiency increased to the 90.1-2010 standard.	Houston	67.1	5.48	1.3%	1.4%	**-0.1%**
	Chicago	89.45	7.02	-0.1%	0.3%	**-0.4%**
	Duluth	120.51	10.63	0.8%	1.2%	**-0.4%**
2. Wall and Roof Insulation to Window Type						
Wall and roof insulation reduced by 10% from baseline and windows upgraded to the 90.1-2010 standard.	Houston	68.33	5.59	-0.5%	-0.5%	**0.1%**
	Chicago	89.99	7.1	-0.7%	-0.9%	**0.2%**
	Duluth	119.71	10.6	1.4%	1.5%	**-0.1%**
3. Wall and Roof Insulation to LPD						
Wall and roof insulation reduced by 10% from baseline and lighting power density upgraded to the 90.1-2010 standard.	Houston	66.81	5.48	1.8%	1.4%	**0.3%**
	Chicago	90.08	7.08	-0.8%	-0.6%	**-0.2%**
	Duluth	122.82	10.86	-1.1%	-0.9%	**-0.2%**
4. Window type to Equipment Efficiency						
Window U and SHGC increased by 10% from baseline and equipment efficiency increased to the 90.1-2010 standard.	Houston	66.14	5.4	2.7%	2.9%	**-0.1%**
	Chicago	94.53	7.39	-5.8%	-5.0%	**-0.8%**
	Duluth	127.56	11.15	-5.0%	-3.6%	**-1.4%**
5. Window type to LPD						
Window U and SHGC increased by 10% from baseline and lighting power density upgraded to the 90.1-2010 standard.	Houston	65.76	5.39	3.3%	3.1%	**0.2%**
	Chicago	95.76	7.49	-7.1%	-6.4%	**-0.7%**
	Duluth	130.25	11.4	-7.2%	-5.9%	**-1.3%**
6. LPD to Equipment Efficiency						
Lighting power density increased by 10% from baseline and equipment efficiency increased to the 90.1-2010 standard.	Houston	68.03	5.55	0.0%	0.2%	**-0.2%**
	Chicago	88.8	6.99	0.7%	0.7%	**-0.1%**
	Duluth	119.19	10.55	1.9%	2.0%	**-0.1%**

The QuickSim method shows consistent positive results for the three building types. The average compliance index delta over all the 126 simulation cases is 0.25%, which is very small considering the simulation is being run for only 4 weeks of the entire year.

4.2 Sensitivity Analysis

The sensitivity analysis tracks the response of the QuickSim method to changes in magnitude of the trade-off components. Section 3.4.2 describes the sensitivity analysis test setup in detail. For each building type, six performance levels are created within every trade-off case. The variation in the compliance indices of the QuickSim method compared to the annual simulation is documented in the sensitivity analysis tables for each building type. A trend graph is plotted showing the change in compliance index with a change in the performance level.

Trade-off case 4 presented a special case because of the limitations on the available choice of window types and equipment efficiencies. To create six performance levels, the three available equipment efficiencies (Standard 90.1-2004, 90.1-2007 and 90.1-2010) would have to be combined with at least two unique window types for a given climate location and building type. These two window types were chosen from the PNNL window library such that, each successively improved over the 90.1-2004 baseline for a given climate location and building type. These two windows and their respective U-values and SHGCs are shown in Table 6.

Table 6: Properties of windows used in trade-off case 4 for sensitivity analysis

Building	Location	90.1-2004 Baseline		Window 1 (w1)		Window 2 (w2)	
		U-Value (h-ft2-F/Btu)	SHGC	U-Value (h-ft2-F/Btu)	SHGC	U-Value (h-ft2-F/Btu)	SHGC
Retail Strip Mall	Houston	1.22	0.25	0.72	0.25	0.62	0.25
	Chicago	0.57	0.49	0.57	0.39	0.42	0.4
	Duluth	0.57	0.49	0.46	0.45	0.33	0.45
Medium Office	Houston	1.22	0.25	0.72	0.25	0.62	0.25
	Chicago	0.57	0.39	0.45	0.31	0.42	0.4
	Duluth	0.57	0.49	0.46	0.45	0.33	0.45
Primary School	Houston	1.22	0.25	0.72	0.25	0.62	0.25
	Chicago	0.62	0.39	0.57	0.39	0.42	0.4
	Duluth	0.62	0.49	0.46	0.45	0.33	0.45

4.2.1 Retail Strip Mall Sensitivity Analysis

Tables 7 through 12 and Figures 1 through 6 show the sensitivity analysis results for the Retail Strip Mall building type. Each table shows one trade-off case and the six performance levels within that trade-off case. The 0% performance level refers to the baseline building, which is assumed to minimally comply with Standard 90.1-2004.

The maximum variation of the compliance index in Table 7 is 0.5%. This maximum delta between the QuickSim and annual index occurs at the two extremes of component levels, i.e., at -30% and 30%. But even at these points, the delta is less than the acceptable threshold of 1.0% difference between annual and QuickSim compliance indices. This result is reflected in all the other trade-off cases as well, where the maximum variation occurs at the extremes of component levels, but still stays within acceptable limits. The maximum variation of compliance index across all the trade-off cases of the Retail Strip Mall prototype is 0.8%.

Figure 1 shows the trend graph of the compliance indices of QuickSim and annual cases from Table 7. The y-axis has been adjusted for uniformity between trend graphs of different trade-off cases for the Retail Strip Mall building type. The 0% performance level is skipped in the graph because it is has no meaning in terms of the compliance index. From the graph, it can be seen that the QuickSim compliance index follows the same trend as the annual compliance index for all three climate locations. This graph shows that the QuickSim response to changes in trade-off components is the same as that of the annual run.

In all the trend graphs, a similar result is seen. The QuickSim compliance index closely follows the trend set by the annual compliance index. The consistency of this result across all the trade-off cases shows that the QuickSim method is insensitive to large changes in magnitude of different trade-off components. Its response to these changes is linear with a small error that may be ignored for the purposes of determining the compliance index.

Table 7: Retail Strip Mall sensitivity analysis for trade-off case 1

Case/Trade-off Description	Location	Perf. Level % from baseline	EUI		Compliance Index		% Delta
			Annual	QuickSim	Annual	QuickSim	
1. Wall and Roof Insulation to Equipment Efficiency							
Baseline: Std. 90.1-2004 building Trade-off building: Wall and roof insulation varied from -30% to +30% compared to baseline. Equipment efficiency fixed at Standard 90.1-2010.	Chicago	**0%**	**100.51**	**7.84**	-	-	-
		-30%	104.57	8.12	-4.0%	-3.7%	**-0.4%**
		-20%	102.97	8.00	-2.5%	-2.1%	**-0.4%**
		-10%	101.40	7.89	-0.9%	-0.6%	**-0.2%**
		10%	98.36	7.65	2.1%	2.4%	**-0.2%**
		20%	96.87	7.54	3.6%	3.9%	**-0.2%**
		30%	95.45	7.41	5.0%	5.5%	**-0.4%**
	Duluth	**0%**	**134.40**	**11.76**			
		-30%	141.53	12.34	-5.3%	-4.9%	**-0.4%**
		-20%	139.11	12.13	-3.5%	-3.2%	**-0.4%**
		-10%	136.66	11.94	-1.7%	-1.5%	**-0.2%**
		10%	131.52	11.53	2.1%	1.9%	**0.2%**
		20%	128.89	11.33	4.1%	3.7%	**0.4%**
		30%	126.17	11.10	6.1%	5.6%	**0.5%**
	Houston	**0%**	**70.49**	**5.67**			
		-30%	71.37	5.72	-1.2%	-0.9%	**-0.4%**
		-20%	70.52	5.66	0.0%	0.2%	**-0.3%**
		-10%	69.68	5.60	1.1%	1.3%	**-0.2%**
		10%	67.97	5.47	3.6%	3.6%	**0.0%**
		20%	67.11	5.40	4.8%	4.7%	**0.1%**
		30%	66.28	5.34	6.0%	5.8%	**0.1%**

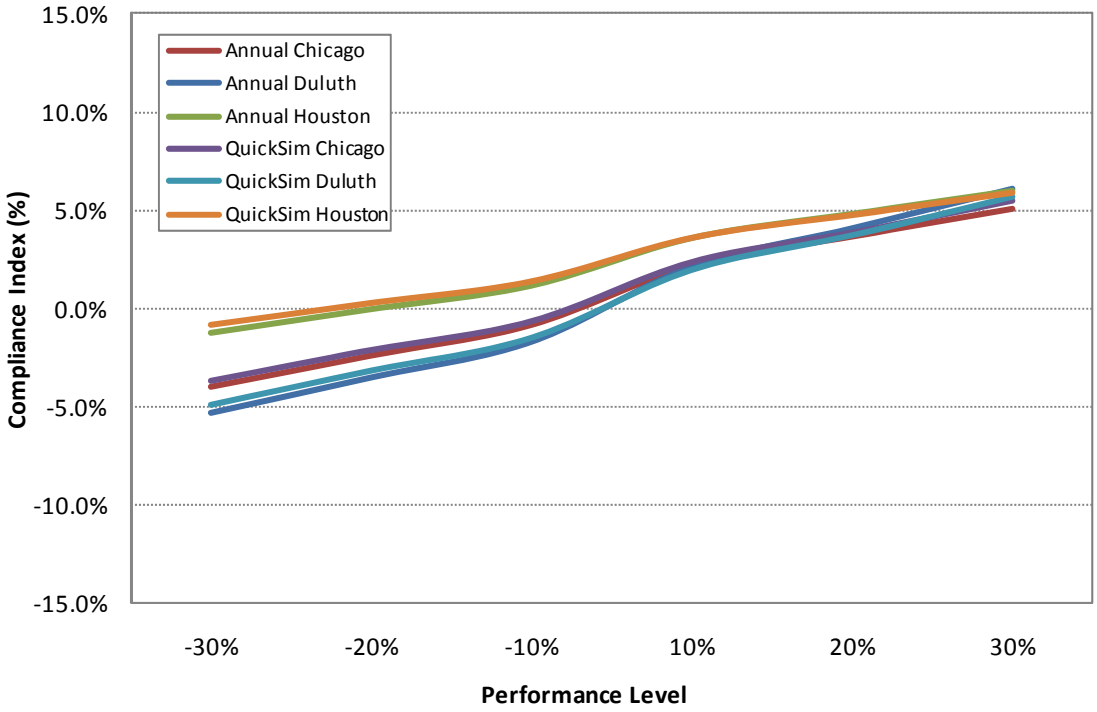

Figure 1: Retail Strip Mall compliance index trend for trade-off case 1 (Table 7)

Table 8: Retail Strip Mall sensitivity analysis for trade-off case 2

Case/Trade-off Description	Location	Perf. Level % from baseline	EUI		Compliance Index		% Delta
			Annual	QuickSim	Annual	QuickSim	
2. Wall and Roof Insulation to Window Type							
Baseline: Std. 90.1-2004 building Trade-off building: Wall and roof insulation varied from -30% to +30% compared to baseline. Window type fixed at Standard 90.1-2004.	Chicago	**0%**	**100.51**	**7.84**			
		-30%	105.26	8.20	-4.7%	-4.6%	**-0.2%**
		-20%	103.65	8.07	-3.1%	-3.0%	**-0.1%**
		-10%	102.07	7.96	-1.6%	-1.5%	**0.0%**
		10%	99.01	7.72	1.5%	1.5%	**0.0%**
		20%	97.51	7.60	3.0%	3.0%	**0.0%**
		30%	96.08	7.47	4.4%	4.7%	**-0.2%**
	Duluth	**0%**	**134.40**	**11.76**			
		-30%	141.80	12.35	-5.5%	-5.0%	**-0.5%**
		-20%	139.38	12.15	-3.7%	-3.3%	**-0.4%**
		-10%	136.92	11.95	-1.9%	-1.6%	**-0.3%**
		10%	131.78	11.55	2.0%	1.8%	**0.1%**
		20%	129.14	11.34	3.9%	3.6%	**0.3%**
		30%	126.42	11.12	5.9%	5.5%	**0.4%**
	Houston	**0%**	**70.49**	**5.67**			
		-30%	73.15	5.87	-3.8%	-3.5%	**-0.3%**
		-20%	72.26	5.80	-2.5%	-2.3%	**-0.2%**
		-10%	71.38	5.74	-1.3%	-1.2%	**-0.1%**
		10%	69.59	5.61	1.3%	1.2%	**0.1%**
		20%	68.60	5.53	2.7%	2.5%	**0.2%**
		30%	67.73	5.46	3.9%	3.7%	**0.2%**

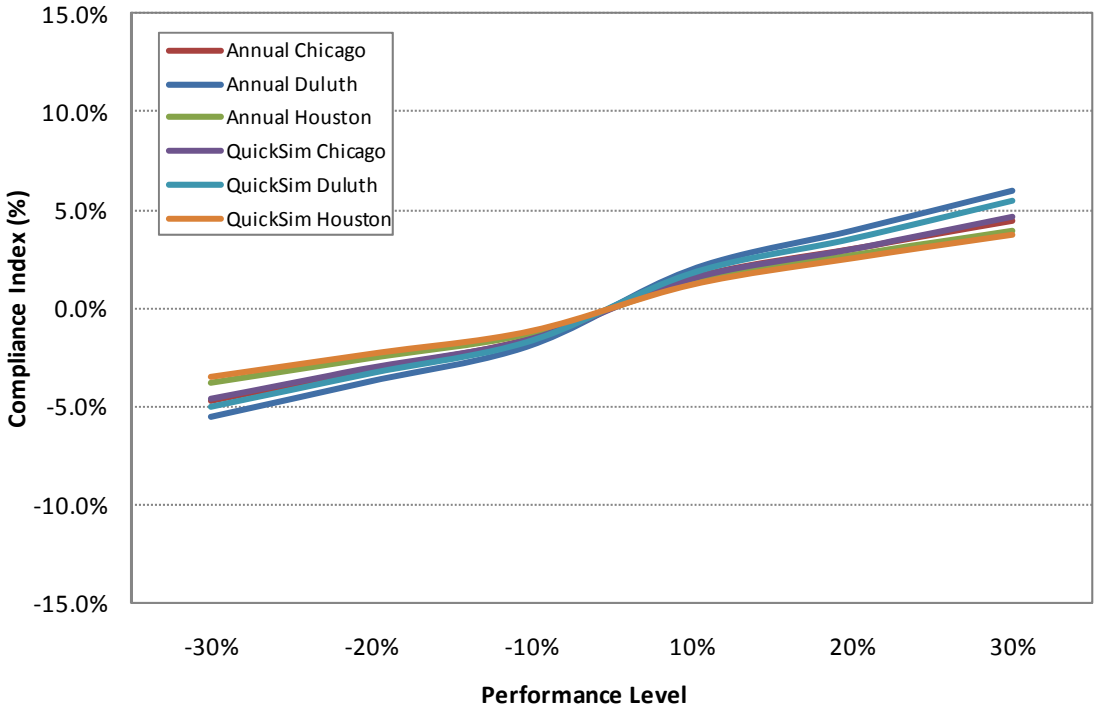

Figure 2: Retail Strip Mall compliance index trend for trade-off case 2 (Table 8)

Table 9: Retail Strip Mall sensitivity analysis for trade-off case 3

Case/Trade-off Description	Location	Perf. Level % from baseline	EUI		Compliance Index		% Delta
			Annual	QuickSim	Annual	QuickSim	
3. Wall and Roof Insulation to LPD							
Baseline: Std. 90.1-2004 building Trade-off building: Wall and roof insulation varied from -30% to +30% compared to baseline. LPD fixed at Standard 90.1-2010.	Chicago	**0%**	**100.51**	**7.84**			
		-30%	103.03	8.00	-2.5%	-2.0%	**-0.5%**
		-20%	101.42	7.87	-0.9%	-0.5%	**-0.5%**
		-10%	99.82	7.76	0.7%	1.0%	**-0.3%**
		10%	96.73	7.52	3.8%	4.1%	**-0.4%**
		20%	95.23	7.40	5.3%	5.6%	**-0.3%**
		30%	93.78	7.27	6.7%	7.2%	**-0.5%**
	Duluth	**0%**	**134.40**	**11.76**			
		-30%	140.27	12.23	-4.4%	-3.9%	**-0.4%**
		-20%	137.84	12.03	-2.6%	-2.3%	**-0.3%**
		-10%	135.40	11.84	-0.7%	-0.7%	**-0.1%**
		10%	130.25	11.44	3.1%	2.7%	**0.4%**
		20%	127.59	11.23	5.1%	4.5%	**0.5%**
		30%	124.88	11.00	7.1%	6.5%	**0.6%**
	Houston	**0%**	**70.49**	**5.67**			
		-30%	68.81	5.53	2.4%	2.4%	**-0.1%**
		-20%	67.90	5.47	3.7%	3.6%	**0.1%**
		-10%	67.00	5.40	4.9%	4.8%	**0.2%**
		10%	65.20	5.27	7.5%	7.2%	**0.3%**
		20%	64.19	5.19	8.9%	8.5%	**0.4%**
		30%	63.32	5.12	10.2%	9.7%	**0.5%**

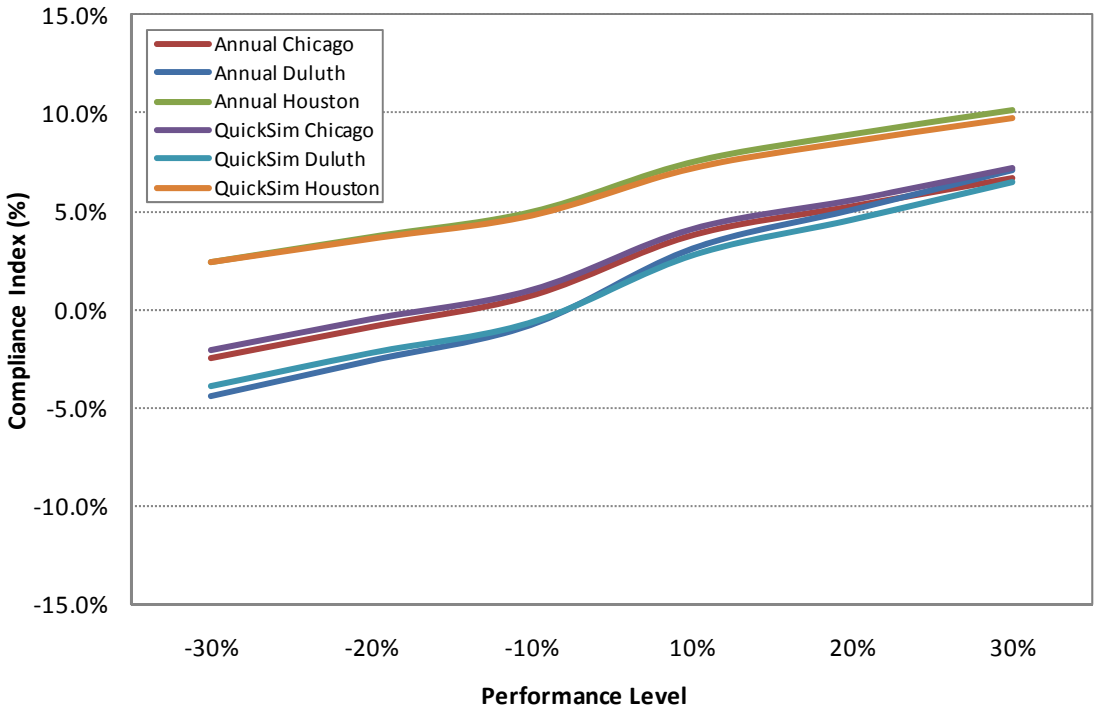

Figure 3: Retail Strip Mall compliance index trend for trade-off case 3 (Table 9)

Table 10: Retail Strip Mall sensitivity analysis for trade-off case 4

Case/Trade-off Description	Location	Perf. Level % from baseline	EUI		Compliance Index		% Delta
			Annual	QuickSim	Annual	QuickSim	
4. Window type to Equipment Efficiency							
Baseline: Std. 90.1-2004 building Trade-off building: Six performance levels obtained by switching between three equipment efficiencies (2004, 2007, 2010) and three window types. The six performance levels are described below in pairs of equipment efficiency and window type. Level 0: EE-2004, baseline Level 1: EE-2004, w1 Level 2: EE-2007, baseline Level 3: EE-2010, baseline Level 4: EE-2004, w2 Level 5: EE-2007, w1 Level 6: EE-2010, w1	Chicago	**Level 0**	**100.51**	**7.84**			
		Level 1	101.06	7.86	-0.5%	-0.3%	**-0.3%**
		Level 2	100.51	7.84	0.0%	0.0%	**0.0%**
		Level 3	99.85	7.77	0.7%	0.9%	**-0.2%**
		Level 4	99.36	7.76	1.1%	1.0%	**0.2%**
		Level 5	101.06	7.86	-0.5%	-0.3%	**-0.3%**
		Level 6	100.41	7.79	0.1%	0.6%	**-0.5%**
	Duluth	**Level 0**	**134.40**	**11.76**			
		Level 1	133.78	11.72	0.5%	0.3%	**0.1%**
		Level 2	134.40	11.76	0.0%	0.0%	**0.0%**
		Level 3	134.14	11.75	0.2%	0.1%	**0.1%**
		Level 4	131.99	11.59	1.8%	1.5%	**0.3%**
		Level 5	133.78	11.72	0.5%	0.3%	**0.1%**
		Level 6	133.52	11.71	0.6%	0.5%	**0.2%**
	Houston	**Level 0**	**70.49**	**5.67**			
		Level 1	70.16	5.65	0.5%	0.5%	**0.0%**
		Level 2	70.49	5.67	0.0%	0.0%	**0.0%**
		Level 3	68.83	5.53	2.4%	2.4%	**-0.1%**
		Level 4	69.59	5.61	1.3%	1.2%	**0.1%**
		Level 5	70.16	5.65	0.5%	0.5%	**0.0%**
		Level 6	68.50	5.51	2.8%	2.9%	**-0.1%**

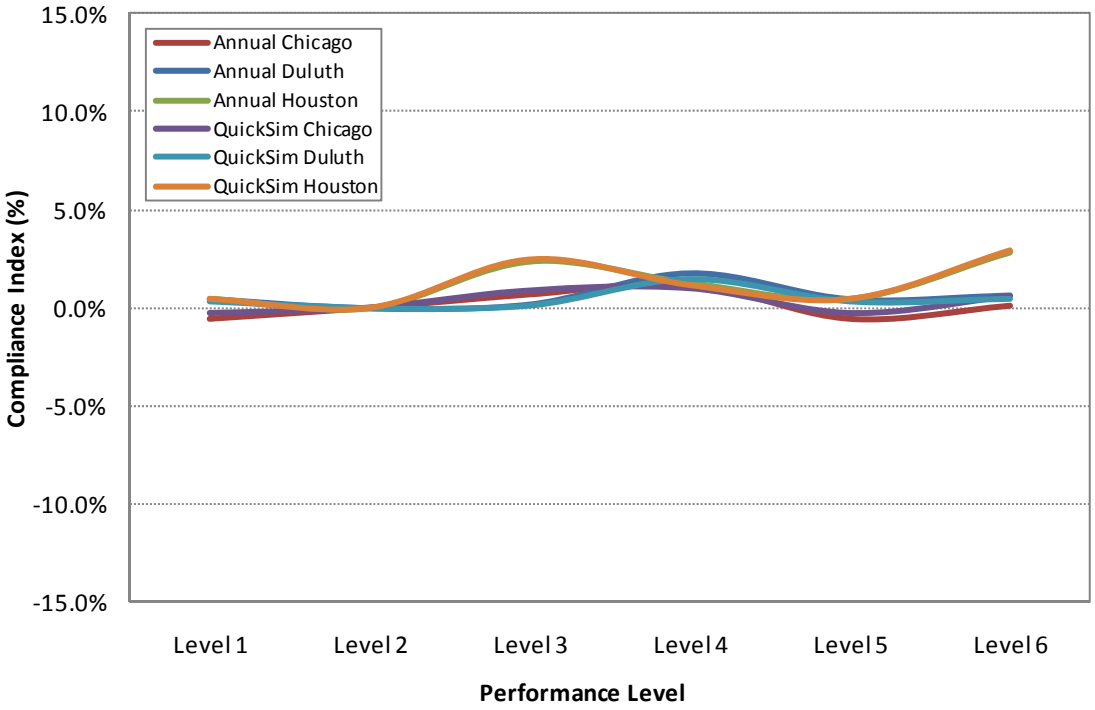

Figure 4: Retail Strip Mall compliance index trend for trade-off case 4 (Table 10)

Table 11: Retail Strip Mall sensitivity analysis for trade-off case 5

Case/Trade-off Description	Location	Perf. Level % from baseline	EUI		Compliance Index		% Delta
			Annual	QuickSim	Annual	QuickSim	
5. Window type to LPD							
Baseline: Std. 90.1-2004 building Trade-off building: LPD varied from -30% to +30% compared to baseline. Window type is fixed at Standard 90.1-2004.	Chicago	**0%**	**100.51**	**7.84**			
		-30%	96.16	7.45	4.3%	4.9%	**-0.6%**
		-20%	97.60	7.58	2.9%	3.3%	**-0.4%**
		-10%	99.04	7.71	1.5%	1.7%	**-0.2%**
		10%	102.04	7.98	-1.5%	-1.8%	**0.2%**
		20%	103.61	8.11	-3.1%	-3.5%	**0.4%**
		30%	105.19	8.26	-4.7%	-5.3%	**0.7%**
	Duluth	**0%**	**134.40**	**11.76**			
		-30%	131.51	11.53	2.1%	2.0%	**0.2%**
		-20%	132.46	11.61	1.4%	1.3%	**0.1%**
		-10%	133.39	11.68	0.8%	0.7%	**0.0%**
		10%	135.37	11.84	-0.7%	-0.7%	**-0.1%**
		20%	136.39	11.91	-1.5%	-1.3%	**-0.2%**
		30%	137.42	12.00	-2.2%	-2.0%	**-0.2%**
	Houston	**0%**	**70.49**	**5.67**			
		-30%	61.86	5.00	12.2%	11.8%	**0.5%**
		-20%	64.79	5.23	8.1%	7.7%	**0.3%**
		-10%	67.62	5.45	4.1%	3.9%	**0.2%**
		10%	73.37	5.89	-4.1%	-3.9%	**-0.2%**
		20%	76.25	6.12	-8.2%	-7.8%	**-0.3%**
		30%	79.14	6.34	-12.3%	-11.8%	**-0.5%**

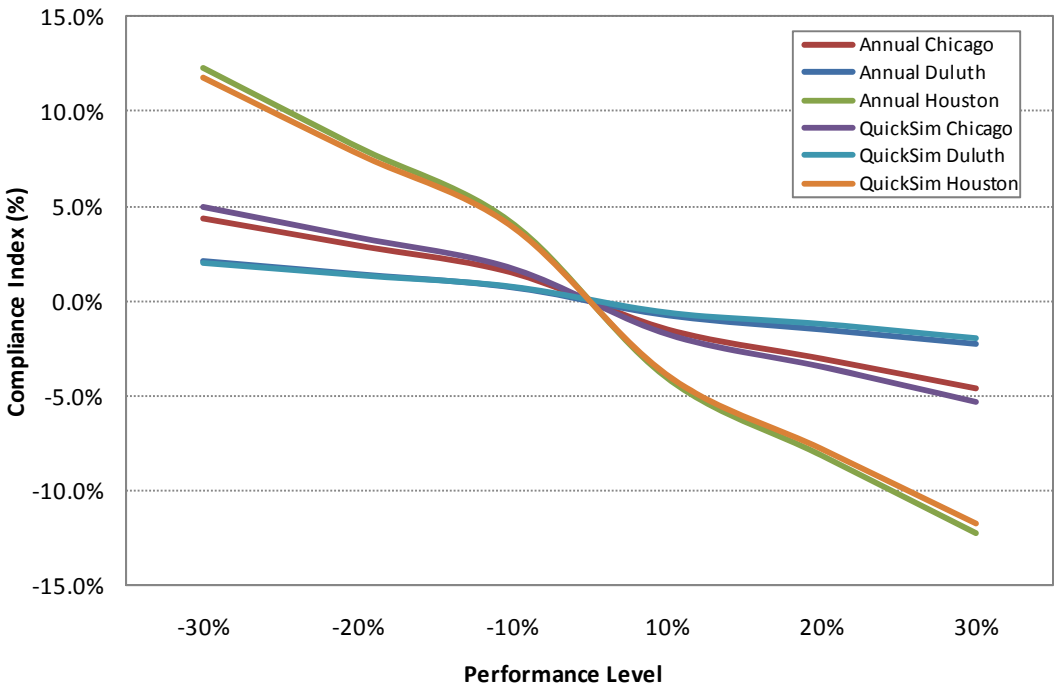

Figure 5: Retail Strip Mall compliance index trend for trade-off case 5 (Table 11)

Table 12: Retail Strip Mall sensitivity analysis for trade-off case 6

Case/Trade-off Description	Location	Perf. Level % from baseline	EUI		Compliance Index		% Delta
			Annual	QuickSim	Annual	QuickSim	
6. LPD to Equipment Efficiency							
Baseline: Std. 90.1-2004 building Trade-off building: LPD varied from -30% to +30% compared to baseline. Equipment efficiency fixed at Standard 90.1-2010.	Chicago	**0%**	**100.51**	**7.84**			
		-30%	95.56	7.39	4.9%	5.7%	**-0.8%**
		-20%	96.97	7.51	3.5%	4.1%	**-0.6%**
		-10%	98.40	7.64	2.1%	2.5%	**-0.4%**
		10%	101.36	7.91	-0.8%	-0.9%	**0.0%**
		20%	102.90	8.04	-2.4%	-2.5%	**0.2%**
		30%	104.46	8.18	-3.9%	-4.4%	**0.4%**
	Duluth	**0%**	**134.40**	**11.76**			
		-30%	131.29	11.52	2.3%	2.1%	**0.2%**
		-20%	132.22	11.59	1.6%	1.4%	**0.2%**
		-10%	133.14	11.67	0.9%	0.8%	**0.1%**
		10%	135.10	11.82	-0.5%	-0.5%	**0.0%**
		20%	136.11	11.89	-1.3%	-1.1%	**-0.2%**
		30%	137.12	11.98	-2.0%	-1.9%	**-0.2%**
	Houston	**0%**	**70.49**	**5.67**			
		-30%	60.46	4.89	14.2%	13.8%	**0.4%**
		-20%	63.25	5.10	10.3%	10.0%	**0.2%**
		-10%	66.03	5.32	6.3%	6.2%	**0.1%**
		10%	71.64	5.75	-1.6%	-1.4%	**-0.3%**
		20%	74.46	5.97	-5.6%	-5.2%	**-0.4%**
		30%	77.29	6.19	-9.7%	-9.1%	**-0.6%**

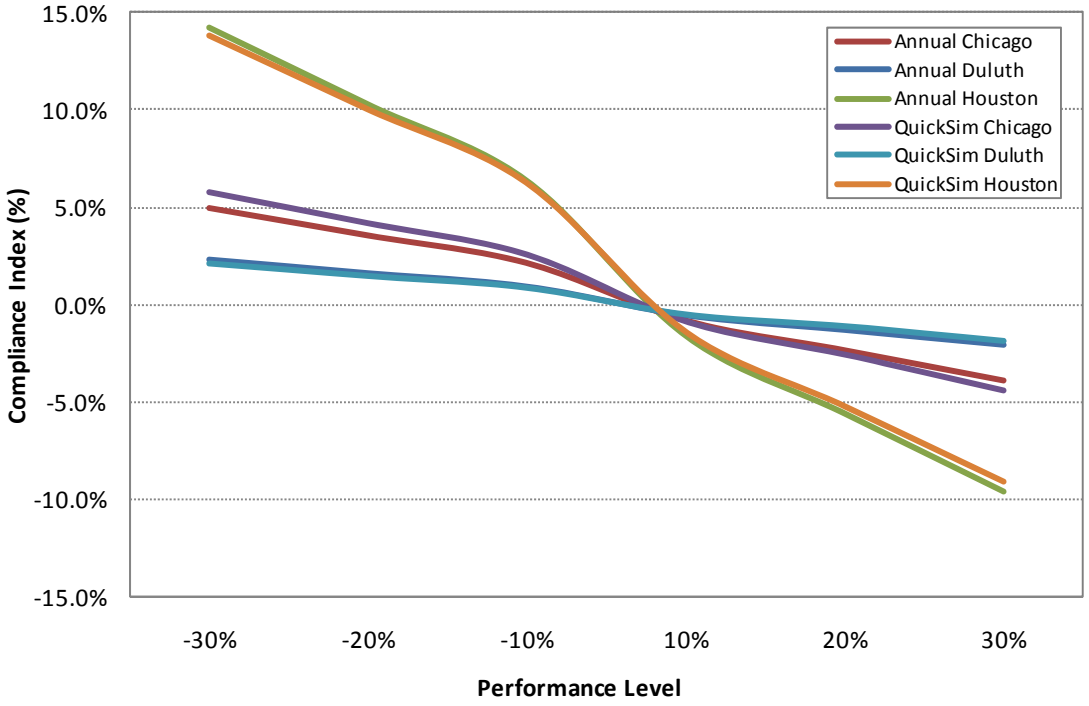

Figure 6: Retail Strip Mall compliance index trend for trade-off case 6 (Table 12)

4.2.2 Medium Office Sensitivity Analysis

Tables 13 through 18 and Figures 7 through 12 show the sensitivity analysis results for the Medium Office building type. Each table shows one trade-off case and the six performance levels within the trade-off case. The 0% performance level refers to the baseline building, which is assumed to minimally comply with Standard 90.1-2004.

The sensitivity analysis result of the Medium Office building is similar to the Retail Strip Mall building. The maximum delta between the QuickSim and annual index occurs at the two extremes of component levels, i.e., at -30% and 30%. But even at these points, the delta is less than the acceptable threshold of 1.0% difference between annual and QuickSim compliance indices. This result is reflected in all the other Medium Office trade-off cases as well, where the maximum variation occurs at the extremes of component levels, but still stays with acceptable limits. The maximum variation of the compliance index across all the trade-off cases of the Medium Office building is 0.8%.

The trend graphs of the compliance indices for the Medium Office building are similar to the ones for the Retail Strip Mall building. While the actual trends are different between the two prototypes, the QuickSim compliance index follows the annual index in the same manner as the previous cases. The difference in trends between the two prototypes is because component changes impact the two prototypes differently.

The y-axis has been adjusted for uniformity between trend graphs of different trade-off cases for the Medium Office building. The 0% performance level is skipped in the graph because it is has no meaning in terms of the compliance index. The graphs show that the QuickSim method's response to changes in trade-off components is the same as that of the annual run. The consistency of this result across all the trade-off cases of the Meduim Office building shows that the QuickSim method is insensitive to large changes in magnitude of different trade-off components. Its response to these changes is linear, with a small error that may be ignored for the purposes of determining the compliance index.

Table 13: Medium Office sensitivity analysis for trade-off case 1

Case/Trade-off Description	Location	Perf. Level % from baseline	EUI		Compliance Index		% Delta
			Annual	QuickSim	Annual	QuickSim	
1. Wall and Roof Insulation to Equipment Efficiency							
Baseline: Std. 90.1-2004 building Trade-off building: Wall and roof insulation varied from -30% to +30% compared to baseline. Equipment efficiency fixed at Standard 90.1-2010.	Chicago	**0%**	**49.71**	**4.13**			
		-30%	49.95	4.12	-0.5%	0.1%	**-0.6%**
		-20%	49.57	4.09	0.3%	0.8%	**-0.5%**
		-10%	49.18	4.07	1.1%	1.4%	**-0.4%**
		10%	48.41	4.01	2.6%	2.8%	**-0.2%**
		20%	48.02	3.98	3.4%	3.5%	**-0.1%**
		30%	47.63	3.95	4.2%	4.2%	**0.0%**
	Duluth	**0%**	**55.76**	**4.96**			
		-30%	56.97	5.08	-2.2%	-2.5%	**0.3%**
		-20%	56.47	5.03	-1.3%	-1.5%	**0.3%**
		-10%	55.97	4.98	-0.4%	-0.5%	**0.2%**
		10%	54.96	4.89	1.4%	1.4%	**0.0%**
		20%	54.46	4.84	2.3%	2.5%	**-0.1%**
		30%	53.96	4.79	3.2%	3.5%	**-0.2%**
	Houston	**0%**	**46.84**	**3.88**			
		-30%	45.77	3.78	2.3%	2.5%	**-0.3%**
		-20%	45.56	3.76	2.7%	2.9%	**-0.2%**
		-10%	45.35	3.74	3.2%	3.4%	**-0.2%**
		10%	45.54	3.76	2.8%	3.0%	**-0.3%**
		20%	45.33	3.74	3.2%	3.4%	**-0.2%**
		30%	45.12	3.73	3.7%	3.9%	**-0.2%**

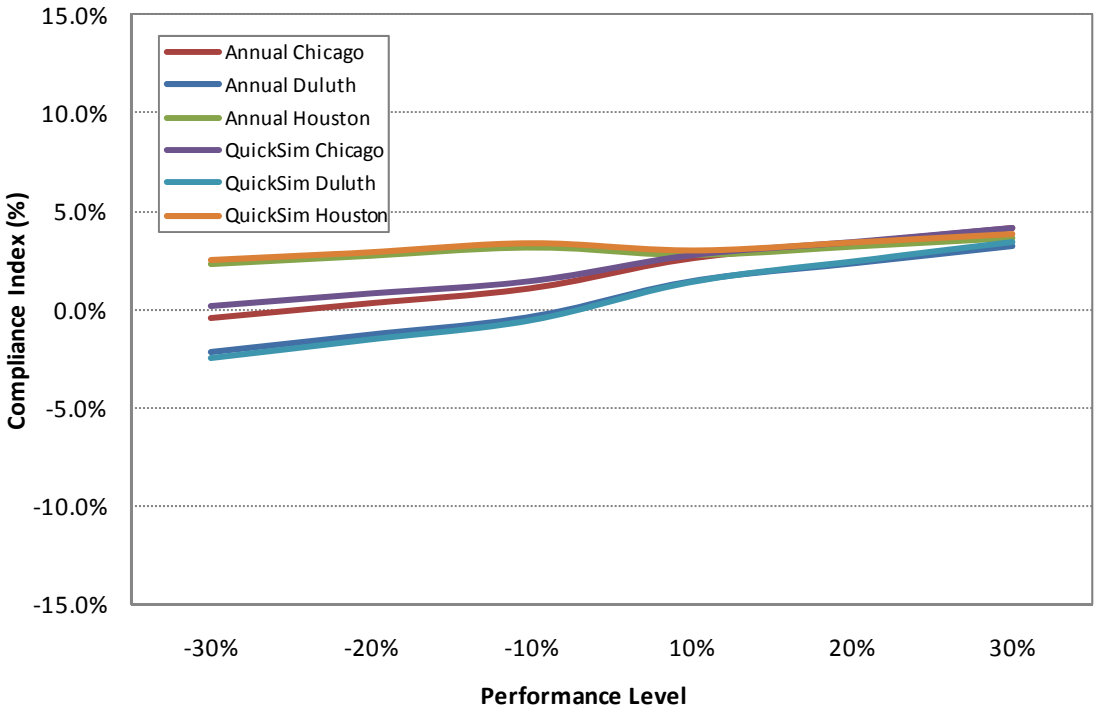

Figure 7: Medium Office compliance index trend for trade-off case 1 (Table 13)

Table 14: Medium Office sensitivity analysis for trade-off case 2

Case/Trade-off Description	Location	Perf. Level % from baseline	EUI		Compliance Index		% Delta
			Annual	QuickSim	Annual	QuickSim	
2. Wall and Roof Insulation to Window Type							
Baseline: Std. 90.1-2004 building Trade-off building: Wall and roof insulation varied from -30% to +30% compared to baseline. Window type fixed at Standard 90.1-2004.	Chicago	**0%**	**49.71**	**4.13**			
		-30%	50.89	4.21	-2.4%	-2.0%	**-0.4%**
		-20%	50.50	4.18	-1.6%	-1.3%	**-0.2%**
		-10%	50.11	4.15	-0.8%	-0.7%	**-0.1%**
		10%	49.32	4.10	0.8%	0.7%	**0.1%**
		20%	48.92	4.07	1.6%	1.4%	**0.2%**
		30%	48.53	4.04	2.4%	2.2%	**0.2%**
	Duluth	**0%**	**55.76**	**4.96**			
		-30%	57.27	5.10	-2.7%	-2.9%	**0.2%**
		-20%	56.77	5.06	-1.8%	-2.0%	**0.2%**
		-10%	56.27	5.01	-0.9%	-1.0%	**0.1%**
		10%	55.25	4.91	0.9%	1.0%	**0.0%**
		20%	54.76	4.86	1.8%	2.0%	**-0.2%**
		30%	54.26	4.81	2.7%	3.0%	**-0.3%**
	Houston	**0%**	**46.84**	**3.88**			
		-30%	47.49	3.93	-1.4%	-1.3%	**-0.1%**
		-20%	47.27	3.91	-0.9%	-0.9%	**0.0%**
		-10%	47.05	3.89	-0.5%	-0.4%	**0.0%**
		10%	46.61	3.86	0.5%	0.4%	**0.0%**
		20%	46.40	3.84	0.9%	0.9%	**0.1%**
		30%	46.18	3.83	1.4%	1.3%	**0.1%**

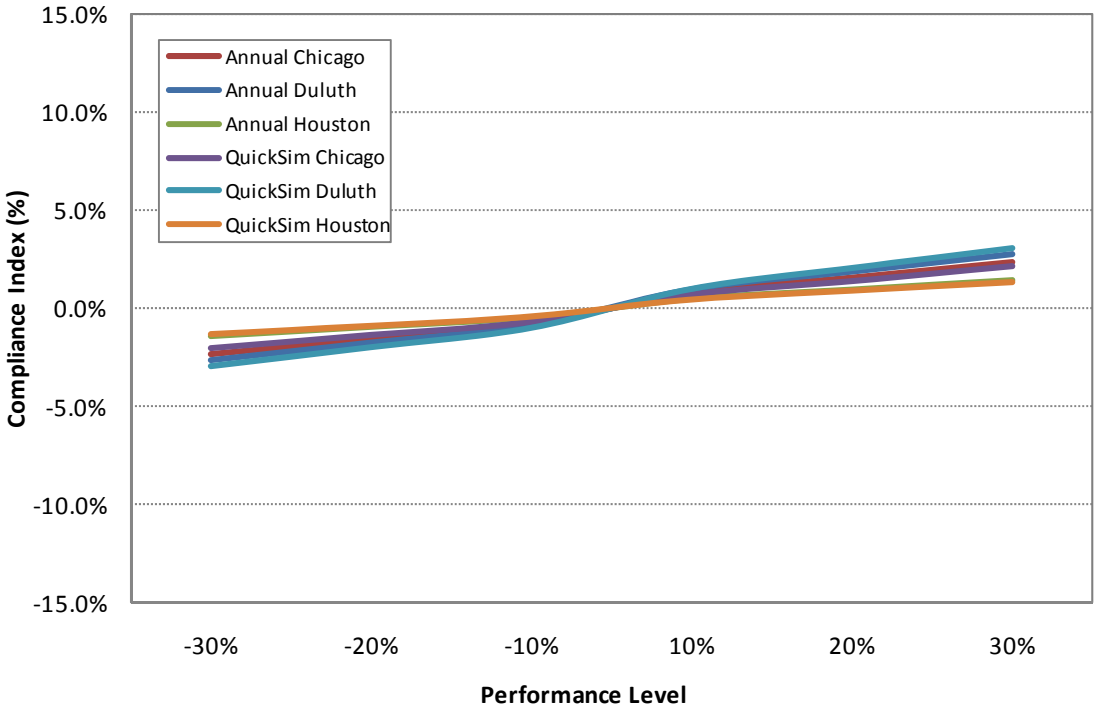

Figure 8: Medium Office compliance index trend for trade-off case 2 (Table 14)

Table 15: Medium Office sensitivity analysis for trade-off case 3

Case/Trade-off Description	Location	Perf. Level % from baseline	EUI		Compliance Index		% Delta
			Annual	QuickSim	Annual	QuickSim	
3. Wall and Roof Insulation to LPD							
Baseline: Std. 90.1-2004 building Trade-off building: Wall and roof insulation varied from -30% to +30% compared to baseline. LPD fixed at Standard 90.1-2010.	Chicago	**0%**	**49.71**	**4.13**			
		-30%	50.24	4.15	-1.1%	-0.7%	**-0.4%**
		-20%	49.86	4.13	-0.3%	0.0%	**-0.3%**
		-10%	49.46	4.10	0.5%	0.6%	**-0.1%**
		10%	48.67	4.04	2.1%	2.0%	**0.1%**
		20%	48.28	4.01	2.9%	2.7%	**0.1%**
		30%	47.88	3.98	3.7%	3.5%	**0.2%**
	Duluth	**0%**	**55.76**	**4.96**			
		-30%	56.71	5.06	-1.7%	-2.0%	**0.3%**
		-20%	56.23	5.01	-0.8%	-1.1%	**0.3%**
		-10%	55.72	4.96	0.1%	-0.1%	**0.2%**
		10%	54.71	4.87	1.9%	1.9%	**0.0%**
		20%	54.20	4.81	2.8%	2.9%	**-0.1%**
		30%	53.70	4.76	3.7%	3.9%	**-0.2%**
	Houston	**0%**	**46.84**	**3.88**			
		-30%	46.63	3.86	0.4%	0.4%	**0.0%**
		-20%	46.41	3.84	0.9%	0.9%	**0.0%**
		-10%	46.19	3.83	1.4%	1.3%	**0.1%**
		10%	45.75	3.79	2.3%	2.2%	**0.1%**
		20%	45.53	3.77	2.8%	2.7%	**0.1%**
		30%	45.30	3.76	3.3%	3.1%	**0.2%**

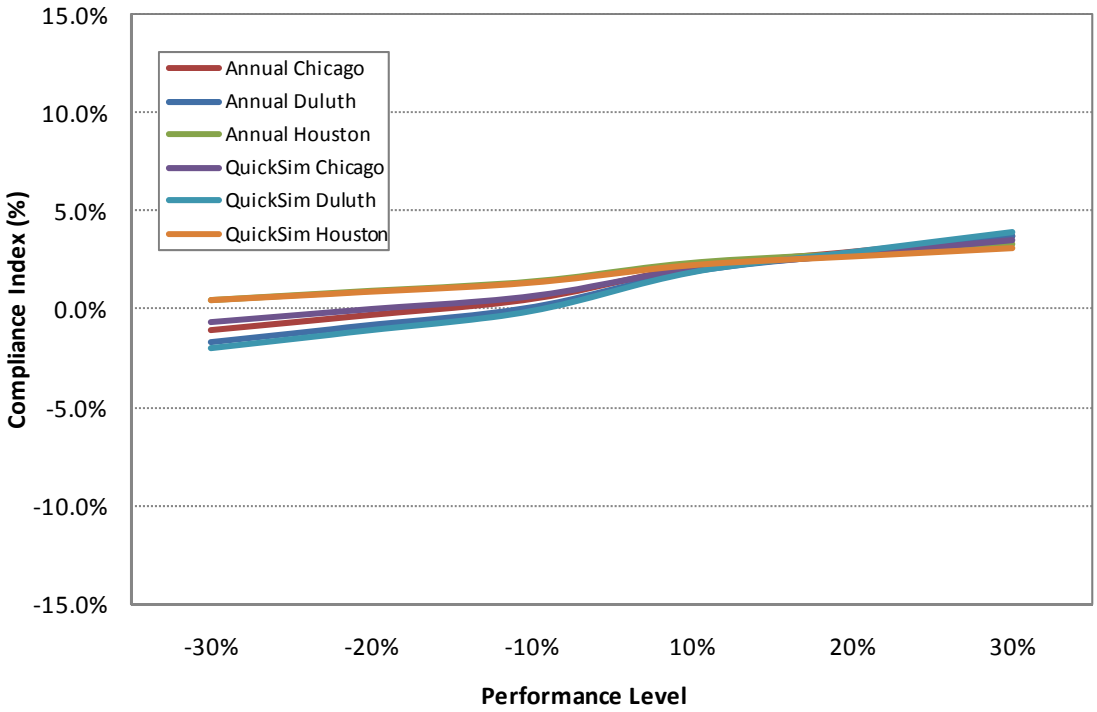

Figure 9: Medium Office compliance index trend for trade-off case 3 (Table 15)

Table 16: Medium Office sensitivity analysis for trade-off case 4

Case/Trade-off Description	Location	Perf. Level % from baseline	EUI		Compliance Index		% Delta
			Annual	QuickSim	Annual	QuickSim	
4. Window type to Equipment Efficiency							
Baseline: Std. 90.1-2004 building Trade-off building: Six performance levels obtained by switching between three equipment efficiencies (2004, 2007, 2010) and three window types. The six performance levels are described below in pairs of equipment efficiency and window type. Level 0: EE-2004, baseline Level 1: EE-2004, w1 Level 2: EE-2007, baseline Level 3: EE-2010, baseline Level 4: EE-2004, w2 Level 5: EE-2007, w1 Level 6: EE-2010, w1	Chicago	**Level 0**	**49.71**	**4.13**			
		Level 1	48.74	4.05	2.0%	1.9%	**0.0%**
		Level 2	49.08	4.07	1.3%	1.4%	**-0.1%**
		Level 3	48.80	4.04	1.8%	2.1%	**-0.2%**
		Level 4	48.14	4.03	3.2%	2.4%	**0.8%**
		Level 5	48.15	3.99	3.1%	3.3%	**-0.1%**
		Level 6	47.88	3.96	3.7%	3.9%	**-0.2%**
	Duluth	**Level 0**	**55.76**	**4.96**			
		Level 1	54.76	4.87	1.8%	1.7%	**0.1%**
		Level 2	55.61	4.95	0.3%	0.2%	**0.0%**
		Level 3	55.46	4.93	0.5%	0.5%	**0.1%**
		Level 4	52.31	4.64	6.2%	6.4%	**-0.2%**
		Level 5	54.61	4.86	2.1%	1.9%	**0.1%**
		Level 6	54.47	4.85	2.3%	2.2%	**0.2%**
	Houston	**Level 0**	**46.84**	**3.88**			
		Level 1	46.52	3.85	0.7%	0.6%	**0.1%**
		Level 2	45.82	3.79	2.2%	2.2%	**0.0%**
		Level 3	45.75	3.78	2.3%	2.6%	**-0.3%**
		Level 4	44.22	3.67	5.6%	5.2%	**0.3%**
		Level 5	45.49	3.77	2.9%	2.8%	**0.1%**
		Level 6	44.82	3.71	4.3%	4.4%	**-0.1%**

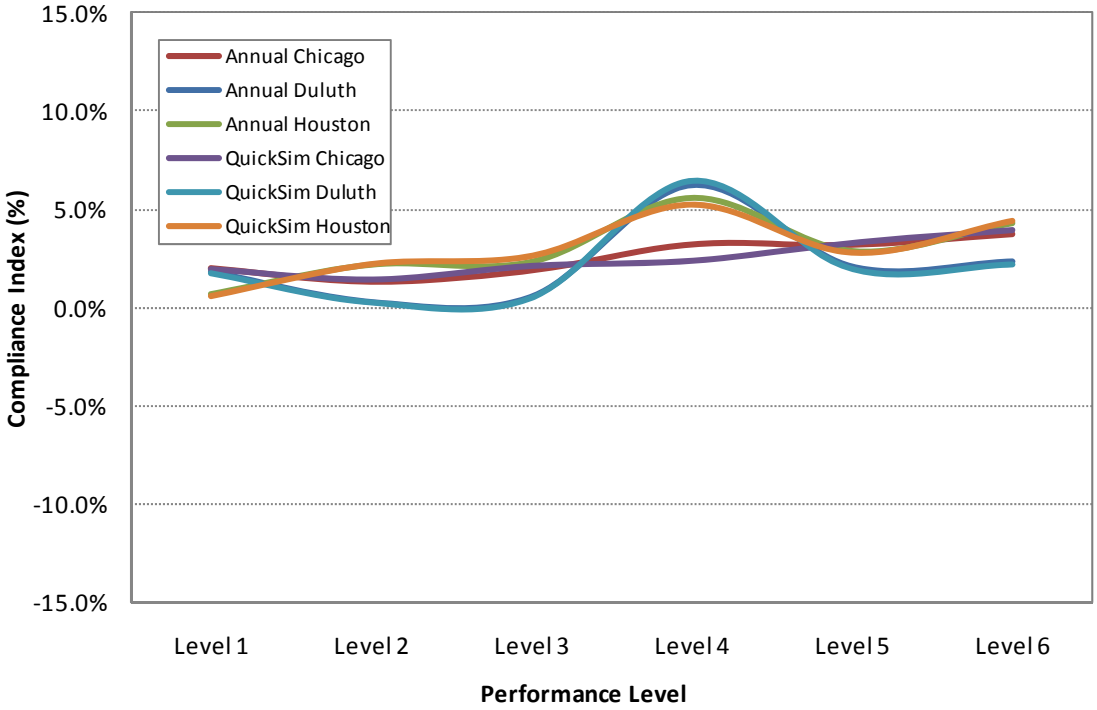

Figure 10: Medium Office compliance index trend for trade-off case 4 (Table 16)

Table 17: Medium Office sensitivity analysis for trade-off case 5

Case/Trade-off Description	Location	Perf. Level % from baseline	EUI		Compliance Index		% Delta
			Annual	QuickSim	Annual	QuickSim	
5. Window type to LPD							
Baseline: Std. 90.1-2004 building Trade-off building: LPD varied from -30% to +30% compared to baseline. Window type is fixed at Standard 90.1-2004.	Chicago	**0%**	**49.71**	**4.13**			
		-30%	47.16	3.91	5.1%	5.3%	**-0.1%**
		-20%	48.00	3.98	3.4%	3.5%	**-0.1%**
		-10%	48.85	4.05	1.7%	1.8%	**-0.1%**
		10%	50.12	4.16	-0.8%	-0.7%	**-0.1%**
		20%	50.97	4.23	-2.5%	-2.5%	**0.0%**
		30%	51.84	4.30	-4.3%	-4.2%	**-0.1%**
	Duluth	**0%**	**55.76**	**4.96**			
		-30%	53.95	4.81	3.3%	2.9%	**0.3%**
		-20%	54.68	4.87	1.9%	1.7%	**0.2%**
		-10%	55.04	4.90	1.3%	1.2%	**0.1%**
		10%	56.50	5.02	-1.3%	-1.2%	**-0.1%**
		20%	57.23	5.08	-2.6%	-2.4%	**-0.2%**
		30%	57.98	5.14	-4.0%	-3.6%	**-0.3%**
	Houston	**0%**	**46.84**	**3.88**			
		-30%	42.93	3.57	8.3%	8.0%	**0.3%**
		-20%	44.54	3.69	4.9%	4.7%	**0.2%**
		-10%	45.69	3.79	2.4%	2.3%	**0.1%**
		10%	47.98	3.97	-2.5%	-2.4%	**-0.1%**
		20%	49.14	4.06	-4.9%	-4.7%	**-0.2%**
		30%	50.30	4.15	-7.4%	-7.1%	**-0.3%**

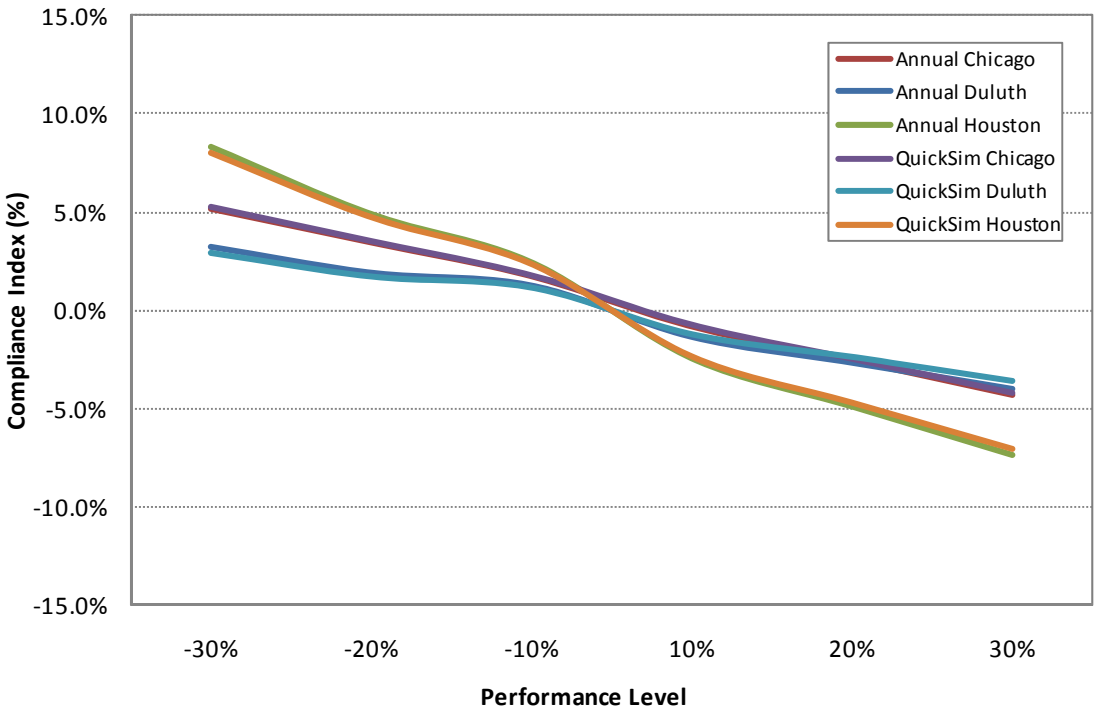

Figure 11: Medium Office compliance index trend for trade-off case 5 (Table 17)

Table 18: Medium Office sensitivity analysis for trade-off case 6

Case/Trade-off Description	Location	Perf. Level % from baseline	EUI		Compliance Index		% Delta
			Annual	QuickSim	Annual	QuickSim	
6. LPD to Equipment Efficiency							
Baseline: Std. 90.1-2004 building Trade-off building: LPD varied from -30% to +30% compared to baseline. Equipment efficiency fixed at Standard 90.1-2010.	Chicago	**0%**	**49.71**	**4.13**			
		-30%	46.65	3.86	6.2%	6.4%	**-0.3%**
		-20%	47.14	3.90	5.2%	5.5%	**-0.3%**
		-10%	47.97	3.97	3.5%	3.8%	**-0.3%**
		10%	49.63	4.11	0.2%	0.4%	**-0.2%**
		20%	50.47	4.18	-1.5%	-1.3%	**-0.2%**
		30%	51.33	4.25	-3.3%	-3.1%	**-0.2%**
	Duluth	**0%**	**55.76**	**4.96**			
		-30%	53.33	4.76	4.4%	4.0%	**0.4%**
		-20%	54.04	4.82	3.1%	2.8%	**0.3%**
		-10%	54.75	4.88	1.8%	1.6%	**0.2%**
		10%	56.19	5.00	-0.8%	-0.8%	**0.0%**
		20%	56.92	5.05	-2.1%	-1.9%	**-0.2%**
		30%	57.65	5.11	-3.4%	-3.1%	**-0.3%**
	Houston	**0%**	**46.84**	**3.88**			
		-30%	42.08	3.48	10.2%	10.1%	**0.0%**
		-20%	43.49	3.60	7.1%	7.2%	**-0.1%**
		-10%	44.62	3.69	4.7%	4.9%	**-0.2%**
		10%	46.26	3.82	1.2%	1.5%	**-0.3%**
		20%	47.37	3.91	-1.1%	-0.8%	**-0.4%**
		30%	48.49	3.99	-3.5%	-3.0%	**-0.5%**

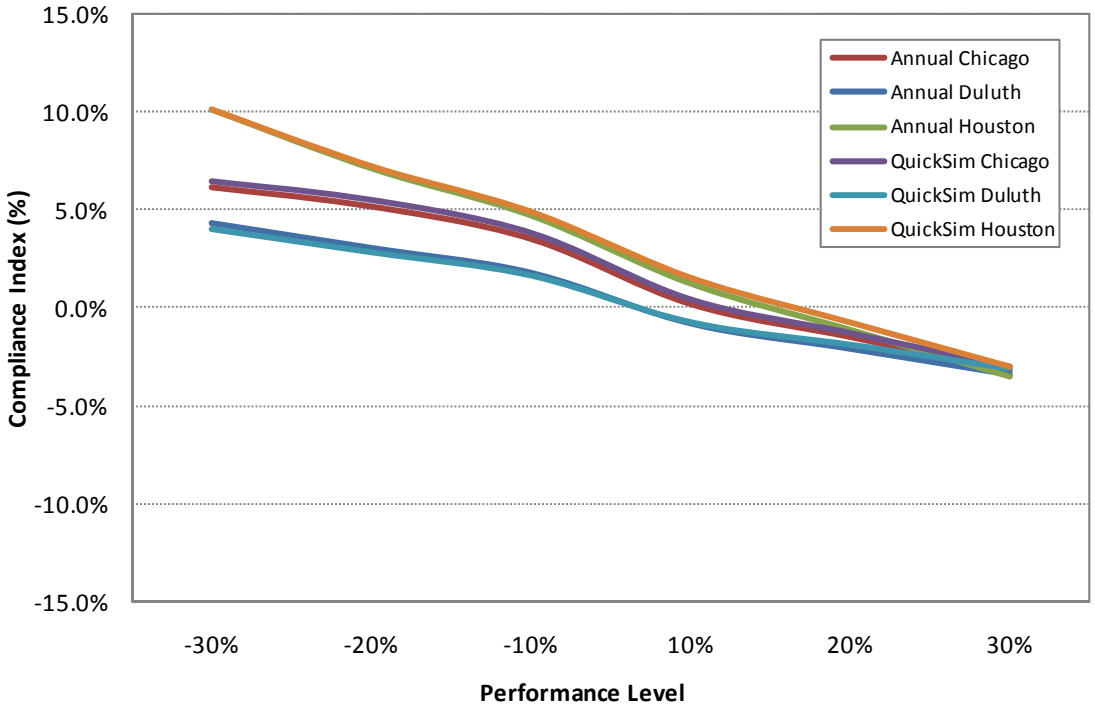

Figure 12: Medium Office compliance index trend for trade-off case 6 (Table 18)

4.2.3 Primary School Sensitivity Analysis

Tables 19 through 24 and Figures 13 through 18 show the sensitivity analysis results for the Primary School building. Each table shows one trade-off case and the six performance levels within the trade-off case. The 0% performance level refers to the baseline building, which is assumed to minimally comply with Standard 90.1-2004.

The sensitivity analysis result of the Primary School building is similar to the previous two building types. There are some differences, however. In trade-off case 4, the compliance index swings by the largest amount amongst all the cases so far. While the QuickSim method follows the same trend and swings by a large amount also, the delta between the two compliance indices rise above 1.0%. The maximum delta is 1.7% and is still only slightly above the acceptable limit. It should be noted also, that this trade-off case, where the equipment efficiency is traded against the window type, is a special case for which the six performance levels were established differently than the other trade-off cases. This can also be observed in the trend graph for this trade-off case as a 'rubber band' effect, which reflects the slightly higher variance in compliance indices.

For the rest of the cases in the Primary School sensitivity analysis, the delta is less than the acceptable threshold of 1.0% difference between annual and QuickSim compliance indices.

The trend graphs of the compliance indices for the Primary School building are similar to the ones for the previous two building types. While the actual trends are different between the two prototypes, the QuickSim compliance index follows the annual index in the same manner as the previous cases.

The y-axis has been adjusted for uniformity between trend graphs of different trade-off cases for the Primary School building. The 0% performance level is skipped in the graph because it is has no meaning in terms of the compliance index.

Table 19: Primary School sensitivity analysis for trade-off case 1

Case/Trade-off Description	Location	Perf. Level % from baseline	EUI		Compliance Index		% Delta
			Annual	QuickSim	Annual	QuickSim	
1. Wall and Roof Insulation to Equipment Efficiency							
Baseline: Std. 90.1-2004 building Trade-off building: Wall and roof insulation varied from -30% to +30% compared to baseline. Equipment efficiency fixed at Standard 90.1-2010.	Chicago	**0%**	**89.39**	**7.04**			
		-30%	92.51	7.24	-3.5%	-2.8%	**-0.7%**
		-20%	91.10	7.13	-1.9%	-1.3%	**-0.6%**
		-10%	89.45	7.02	-0.1%	0.3%	**-0.4%**
		10%	85.45	6.73	4.4%	4.5%	**-0.1%**
		20%	83.45	6.57	6.7%	6.7%	**-0.1%**
		30%	81.58	6.42	8.7%	8.9%	**-0.1%**
	Duluth	**0%**	**121.45**	**10.76**			
		-30%	124.33	10.92	-2.4%	-1.5%	**-0.9%**
		-20%	122.43	10.77	-0.8%	-0.2%	**-0.7%**
		-10%	120.51	10.63	0.8%	1.2%	**-0.4%**
		10%	115.84	10.27	4.6%	4.5%	**0.1%**
		20%	113.06	10.06	6.9%	6.5%	**0.4%**
		30%	109.87	9.80	9.5%	8.9%	**0.7%**
	Houston	**0%**	**68.00**	**5.56**			
		-30%	68.59	5.60	-0.9%	-0.8%	**-0.1%**
		-20%	67.90	5.55	0.1%	0.2%	**0.0%**
		-10%	67.10	5.48	1.3%	1.5%	**-0.2%**
		10%	65.47	5.35	3.7%	3.8%	**-0.1%**
		20%	64.67	5.28	4.9%	4.9%	**-0.1%**
		30%	63.90	5.22	6.0%	6.1%	**0.0%**

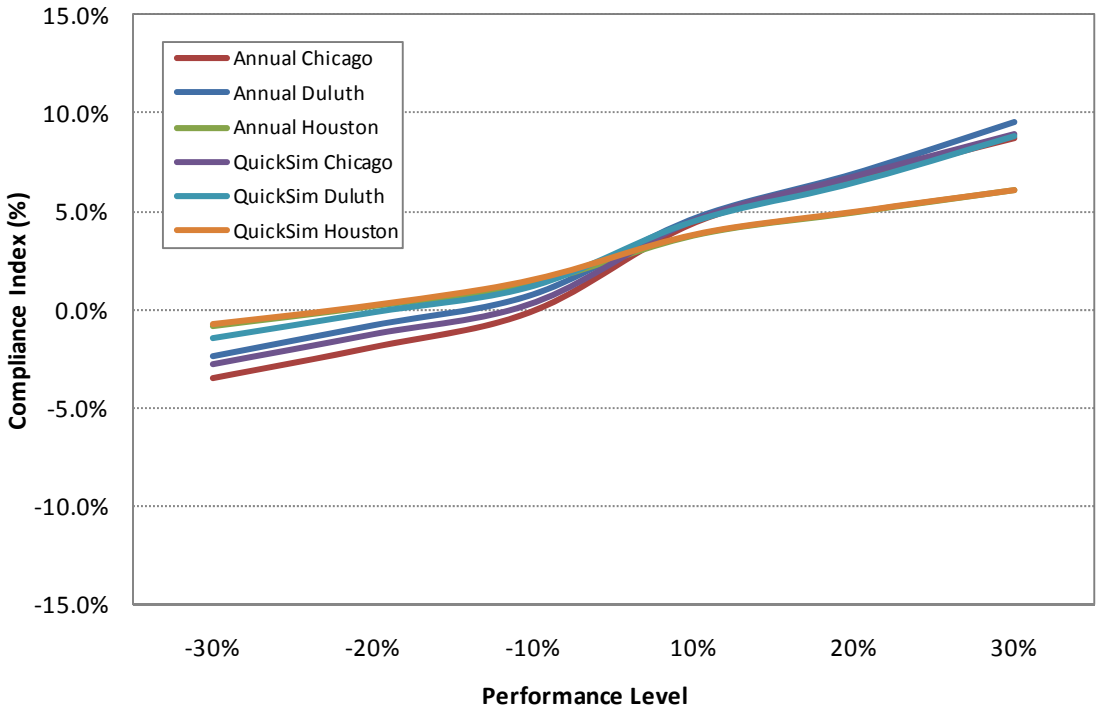

Figure 13: Primary School compliance index trend for trade-off case 1 (Table 19)

Table 20: Primary School sensitivity analysis for trade-off case 2

Case/Trade-off Description	Location	Perf. Level % from baseline	EUI		Compliance Index		% Delta
			Annual	QuickSim	Annual	QuickSim	
2. Wall and Roof Insulation to Window Type							
Baseline: Std. 90.1-2004 building Trade-off building: Wall and roof insulation varied from -30% to +30% compared to baseline. Window type fixed at Standard 90.1-2004.	Chicago	**0%**	**89.39**	**7.04**			
		-30%	94.65	7.42	-5.9%	-5.3%	**-0.5%**
		-20%	93.16	7.31	-4.2%	-3.7%	**-0.5%**
		-10%	91.42	7.19	-2.3%	-2.1%	**-0.2%**
		10%	87.21	6.88	2.4%	2.3%	**0.1%**
		20%	85.11	6.71	4.8%	4.7%	**0.1%**
		30%	83.13	6.55	7.0%	6.9%	**0.1%**
	Duluth	**0%**	**121.45**	**10.76**			
		-30%	127.58	11.22	-5.0%	-4.3%	**-0.7%**
		-20%	125.59	11.07	-3.4%	-2.9%	**-0.5%**
		-10%	123.58	10.92	-1.8%	-1.5%	**-0.3%**
		10%	118.69	10.54	2.3%	2.0%	**0.3%**
		20%	115.76	10.32	4.7%	4.1%	**0.6%**
		30%	112.42	10.05	7.4%	6.6%	**0.8%**
	Houston	**0%**	**68.00**	**5.56**			
		-30%	70.46	5.76	-3.6%	-3.7%	**0.0%**
		-20%	69.73	5.71	-2.6%	-2.7%	**0.1%**
		-10%	68.88	5.63	-1.3%	-1.2%	**-0.1%**
		10%	67.14	5.49	1.3%	1.2%	**0.0%**
		20%	66.29	5.42	2.5%	2.4%	**0.1%**
		30%	65.48	5.36	3.7%	3.6%	**0.1%**

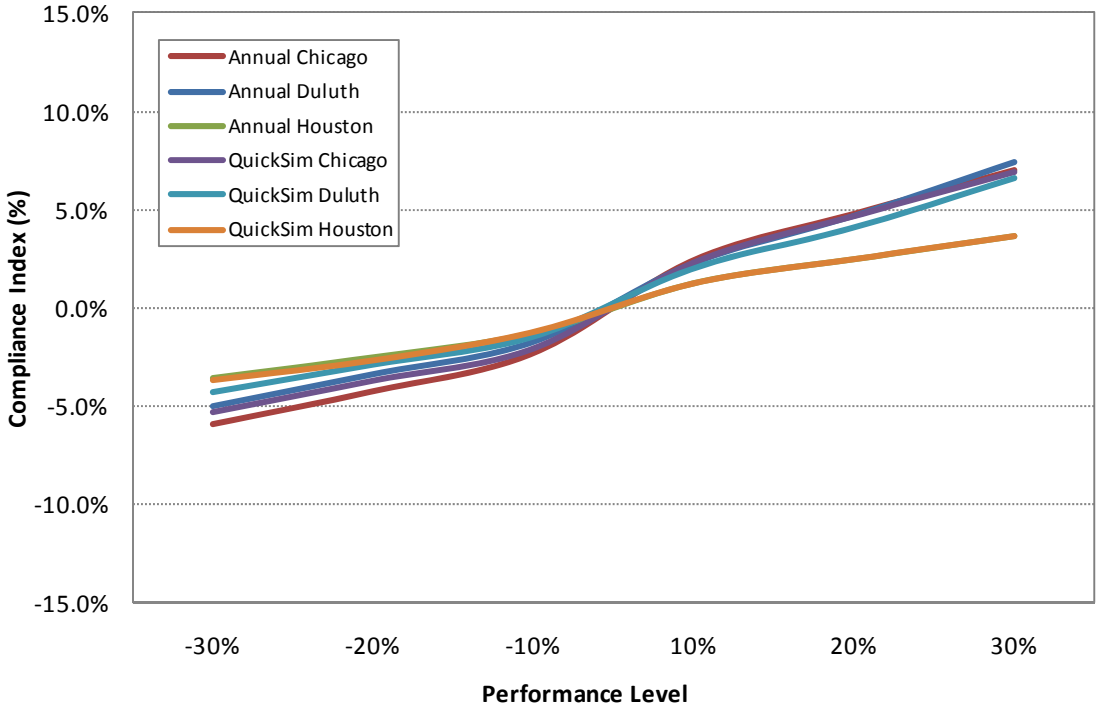

Figure 14: Primary School compliance index trend for trade-off case 2 (Table 20)

Table 21: Primary School sensitivity analysis for trade-off case 3

Case/Trade-off Description	Location	Perf. Level % from baseline	EUI		Compliance Index		% Delta
			Annual	QuickSim	Annual	QuickSim	
3. Wall and Roof Insulation to LPD							
Baseline: Std. 90.1-2004 building Trade-off building: Wall and roof insulation varied from -30% to +30% compared to baseline. LPD fixed at Standard 90.1-2010.	Chicago	**0%**	**89.39**	**7.04**			
		-30%	93.62	7.32	-4.7%	-4.0%	**-0.7%**
		-20%	92.09	7.22	-3.0%	-2.5%	**-0.5%**
		-10%	90.08	7.08	-0.8%	-0.5%	**-0.3%**
		10%	85.70	6.76	4.1%	4.1%	**0.1%**
		20%	83.56	6.59	6.5%	6.4%	**0.1%**
		30%	81.51	6.42	8.8%	8.8%	**0.0%**
	Duluth	**0%**	**121.45**	**10.76**			
		-30%	126.88	11.16	-4.5%	-3.8%	**-0.7%**
		-20%	124.90	11.00	-2.8%	-2.3%	**-0.6%**
		-10%	122.82	10.86	-1.1%	-0.9%	**-0.2%**
		10%	117.48	10.43	3.3%	3.0%	**0.3%**
		20%	114.34	10.19	5.9%	5.3%	**0.6%**
		30%	111.01	9.92	8.6%	7.8%	**0.8%**
	Houston	**0%**	**68.00**	**5.56**			
		-30%	68.54	5.62	-0.8%	-1.1%	**0.3%**
		-20%	67.71	5.55	0.4%	0.1%	**0.3%**
		-10%	66.81	5.48	1.7%	1.4%	**0.3%**
		10%	65.03	5.33	4.4%	4.1%	**0.3%**
		20%	64.17	5.26	5.6%	5.3%	**0.3%**
		30%	63.35	5.20	6.8%	6.5%	**0.3%**

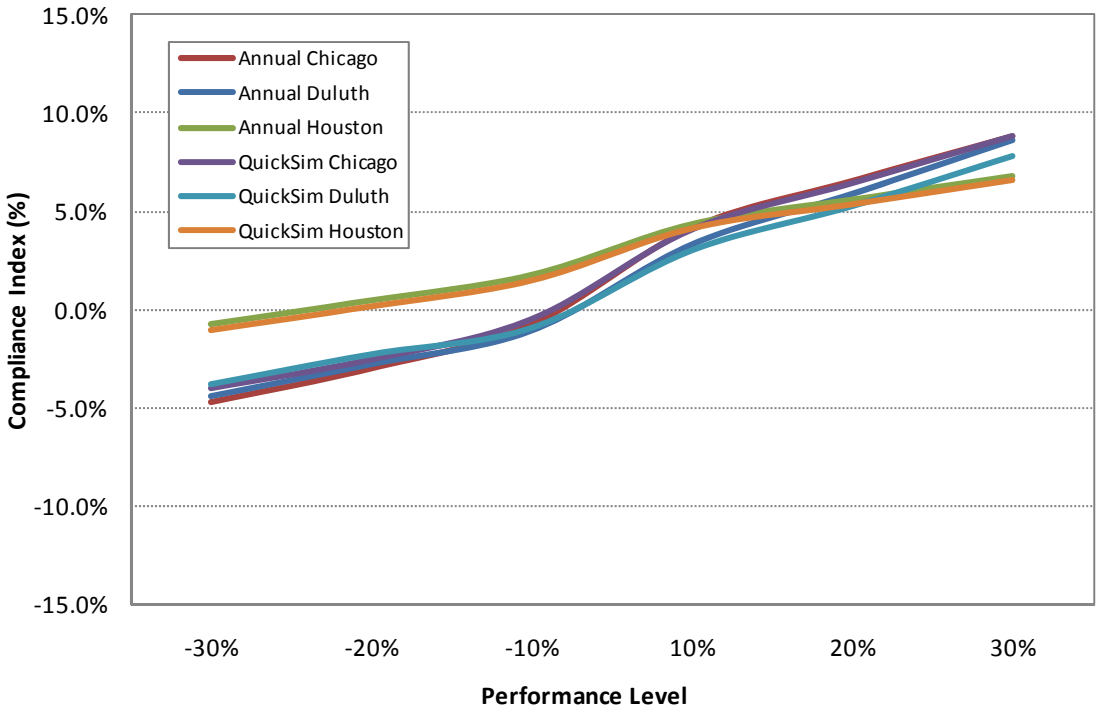

Figure 15: Primary School compliance index trend for trade-off case 3 (Table 21)

Table 22: Primary School sensitivity analysis for trade-off case 4

Case/Trade-off Description	Location	Perf. Level % from baseline	EUI		Compliance Index		% Delta
			Annual	QuickSim	Annual	QuickSim	
4. Window type to Equipment Efficiency							
Baseline: Std. 90.1-2004 building Trade-off building: Six performance levels obtained by switching between three equipment efficiencies (2004, 2007, 2010) and three window types. The six performance levels are described below in pairs of equipment efficiency and window type. Level 0: EE-2004, baseline Level 1: EE-2004, w1 Level 2: EE-2007, baseline Level 3: EE-2010, baseline Level 4: EE-2004, w2 Level 5: EE-2007, w1 Level 6: EE-2010, w1	Chicago	**Level 0**	**89.39**	**7.04**			
		Level 1	89.39	7.04	0.0%	0.0%	**0.0%**
		Level 2	81.87	6.44	8.4%	8.6%	**-0.2%**
		Level 3	87.51	6.88	2.1%	2.3%	**-0.2%**
		Level 4	87.56	6.95	2.0%	1.3%	**0.7%**
		Level 5	81.87	6.44	8.4%	8.6%	**-0.2%**
		Level 6	87.51	6.88	2.1%	2.3%	**-0.2%**
	Duluth	**Level 0**	**121.45**	**10.76**			
		Level 1	119.18	10.59	1.9%	1.6%	**0.3%**
		Level 2	107.09	9.30	11.8%	13.5%	**-1.7%**
		Level 3	118.48	10.48	2.5%	2.6%	**-0.2%**
		Level 4	112.07	10.04	7.7%	6.7%	**1.0%**
		Level 5	105.12	9.15	13.4%	15.0%	**-1.5%**
		Level 6	116.32	10.32	4.2%	4.1%	**0.2%**
	Houston	**Level 0**	**68.00**	**5.56**			
		Level 1	67.48	5.52	0.8%	0.6%	**0.1%**
		Level 2	65.52	5.31	3.6%	4.5%	**-0.9%**
		Level 3	66.27	5.41	2.5%	2.7%	**-0.1%**
		Level 4	65.52	5.38	3.6%	3.3%	**0.4%**
		Level 5	65.04	5.27	4.3%	5.1%	**-0.8%**
		Level 6	65.79	5.38	3.2%	3.3%	**0.0%**

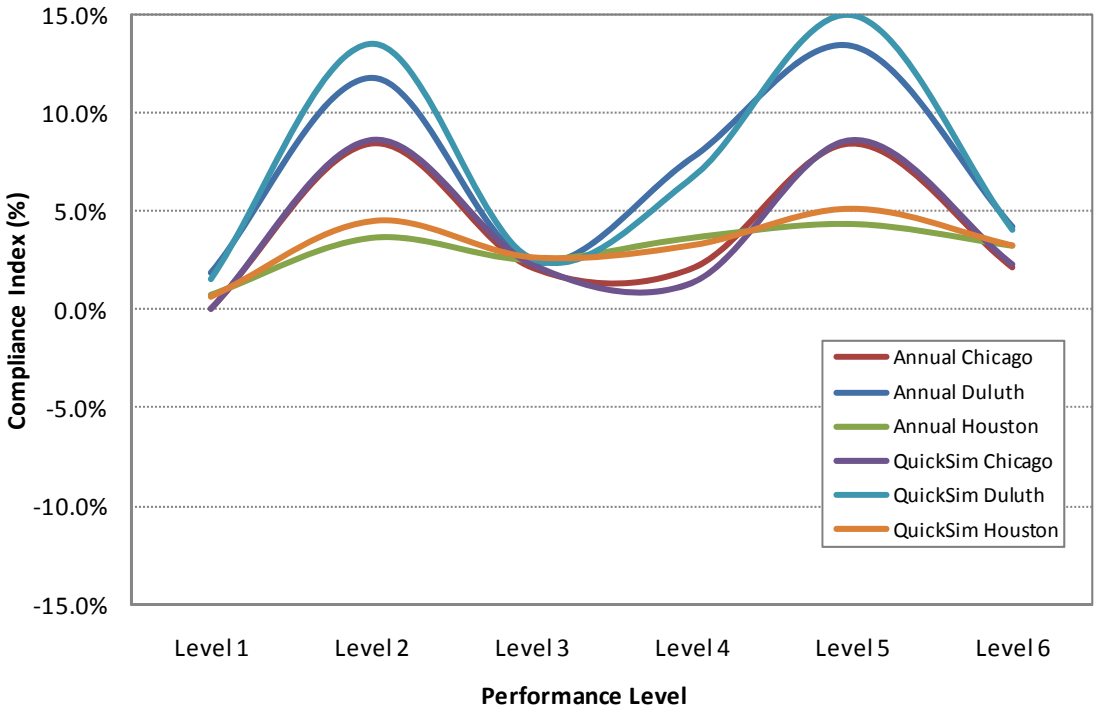

Figure 16: Primary School compliance index trend for trade-off case 4 (Table 22)

Table 23: Primary School sensitivity analysis for trade-off case 5

Case/Trade-off Description	Location	Perf. Level % from baseline	EUI		Compliance Index		% Delta
			Annual	QuickSim	Annual	QuickSim	
5. Window type to LPD							
Baseline: Std. 90.1-2004 building Trade-off building: LPD varied from -30% to +30% compared to baseline. Window type is fixed at Standard 90.1-2004.	Chicago	**0%**	**89.39**	**7.04**			
		-30%	85.58	6.73	4.3%	4.5%	**-0.2%**
		-20%	86.85	6.83	2.8%	3.0%	**-0.2%**
		-10%	88.14	6.93	1.4%	1.6%	**-0.1%**
		10%	90.68	7.15	-1.4%	-1.5%	**0.1%**
		20%	91.84	7.25	-2.7%	-2.9%	**0.2%**
		30%	93.06	7.36	-4.1%	-4.4%	**0.3%**
	Duluth	**0%**	**121.45**	**10.76**			
		-30%	118.55	10.50	2.4%	2.4%	**0.0%**
		-20%	119.59	10.59	1.5%	1.5%	**0.0%**
		-10%	120.59	10.69	0.7%	0.7%	**0.0%**
		10%	122.12	10.83	-0.6%	-0.6%	**0.1%**
		20%	122.75	10.87	-1.1%	-1.1%	**0.0%**
		30%	123.40	10.94	-1.6%	-1.7%	**0.1%**
	Houston	**0%**	**68.00**	**5.56**			
		-30%	62.72	5.16	7.8%	7.2%	**0.6%**
		-20%	64.48	5.29	5.2%	4.8%	**0.4%**
		-10%	66.24	5.43	2.6%	2.4%	**0.2%**
		10%	69.79	5.69	-2.6%	-2.4%	**-0.2%**
		20%	71.58	5.83	-5.3%	-4.9%	**-0.4%**
		30%	73.37	5.96	-7.9%	-7.3%	**-0.6%**

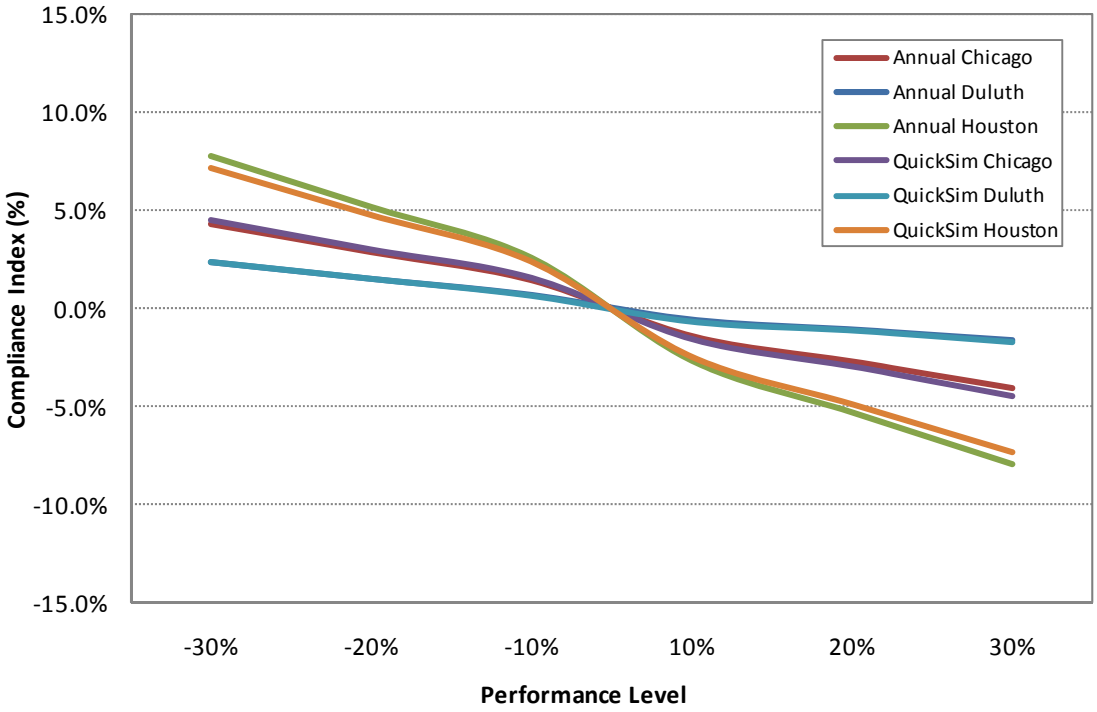

Figure 17: Primary School compliance index trend for trade-off case 5 (Table 23)

Table 24: Primary School sensitivity analysis for trade-off case 6

Case/Trade-off Description	Location	Perf. Level % from baseline	EUI		Compliance Index		% Delta
			Annual	QuickSim	Annual	QuickSim	
6. LPD to Equipment Efficiency							
Baseline: Std. 90.1-2004 building Trade-off building: LPD varied from -30% to +30% compared to baseline. Equipment efficiency fixed at Standard 90.1-2010.	Chicago	**0%**	**89.39**	**7.04**			
		-30%	83.69	6.57	6.4%	6.8%	**-0.4%**
		-20%	84.97	6.67	4.9%	5.3%	**-0.3%**
		-10%	86.25	6.77	3.5%	3.8%	**-0.3%**
		10%	88.80	6.99	0.7%	0.7%	**-0.1%**
		20%	89.97	7.09	-0.6%	-0.6%	**0.0%**
		30%	91.20	7.19	-2.0%	-2.1%	**0.1%**
	Duluth	**0%**	**121.45**	**10.76**			
		-30%	115.51	10.22	4.9%	5.0%	**-0.1%**
		-20%	116.56	10.31	4.0%	4.1%	**-0.1%**
		-10%	117.59	10.40	3.2%	3.3%	**-0.1%**
		10%	119.19	10.55	1.9%	1.9%	**-0.1%**
		20%	119.87	10.60	1.3%	1.5%	**-0.1%**
		30%	120.53	10.67	0.8%	0.9%	**-0.1%**
	Houston	**0%**	**68.00**	**5.56**			
		-30%	61.06	5.02	10.2%	9.7%	**0.5%**
		-20%	62.80	5.15	7.6%	7.4%	**0.3%**
		-10%	64.54	5.28	5.1%	5.0%	**0.1%**
		10%	68.03	5.55	0.0%	0.2%	**-0.3%**
		20%	69.82	5.68	-2.7%	-2.2%	**-0.5%**
		30%	71.57	5.81	-5.3%	-4.6%	**-0.7%**

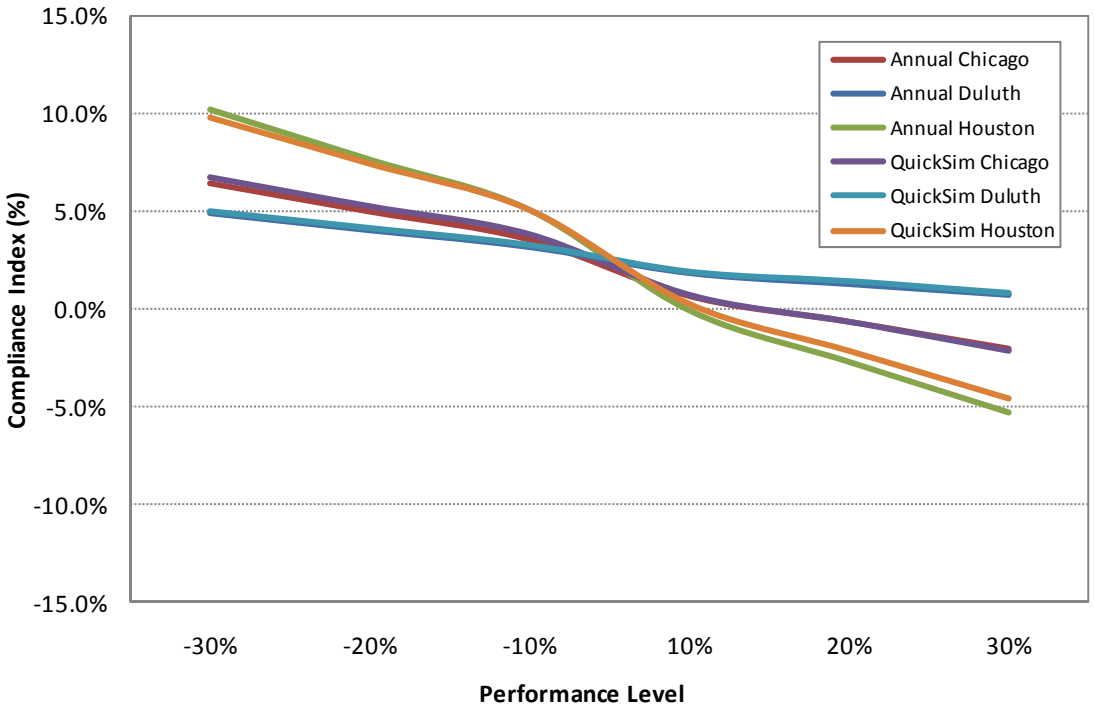

Figure 18: Primary School compliance index trend for trade-off case 6 (Table 24)

4.3 Runtime Comparison

To evaluate the actual saving in runtime from the QuickSim analysis, the trade-off cases created as part of the first test were run on a local Windows computer. The Windows version of EnergyPlus was used. A batch simulation utility is available in EnergyPlus, and it was used to setup the simulation runs. The major specifications of the local workstation used for this test are as follows:

Processor:	Intel Xeon E5530 @ 2.40 GHz
Total Physical Memory:	4.00 GB
Available Physical Memory:	2.89 GB
Page File Space:	4.82 GB

Table 25 below shows the runtimes of the annual and QuickSim simulations for the Retail Strip Mall prototype. The average runtime for the annual run is 2.56 minutes, while that for the QuickSim run is 0.64 minutes. On an average, this represents a reduction in runtime by 75%, or a saving of 1.92 minutes per run.

Table 25: Retail Strip Mall runtime comparison

Case/Trade-off Description	Location	Runtime			
		Annual (min)	QuickSim (min)	Delta (min)	Delta %
Baseline Case	Houston	2.44	0.63	1.81	74%
	Chicago	2.64	0.65	1.99	75%
	Duluth	2.59	0.64	1.94	75%
1. Wall and Roof Insulation to Equipment Efficiency	Houston	2.55	0.63	1.92	75%
	Chicago	2.60	0.65	1.96	75%
	Duluth	2.67	0.67	2.00	75%
2. Wall and Roof Insulation to Window Type	Houston	2.50	0.62	1.87	75%
	Chicago	2.58	0.64	1.94	75%
	Duluth	2.67	0.66	2.01	75%
3. Wall and Roof Insulation to LPD	Houston	2.44	0.62	1.82	75%
	Chicago	2.58	0.64	1.95	75%
	Duluth	2.66	0.66	2.01	75%
4. Window type to Equipment Efficiency	Houston	2.46	0.62	1.85	75%
	Chicago	2.57	0.64	1.93	75%
	Duluth	2.63	0.65	1.98	75%
5. Window type to LPD	Houston	2.46	0.62	1.84	75%
	Chicago	2.56	0.64	1.92	75%
	Duluth	2.63	0.65	1.98	75%
6. LPD to Equipment Efficiency	Houston	2.46	0.62	1.84	75%
	Chicago	2.58	0.64	1.94	75%
	Duluth	2.64	0.65	1.99	75%
Average		**2.56**	**0.64**	**1.92**	**75%**

Table 26 shows the runtimes of the annual and QuickSim simulations for the Medium Office prototype. The average runtime for the annual run is 2.63 minutes, while that for the QuickSim run is 0.72 minutes. On an average, this represents a reduction in runtime by 72%, or a saving of 1.91 minutes per run.

Table 26: Medium Office runtime comparison

Case/Trade-off Description	Location	Runtime			
		Annual (min)	QuickSim (min)	Delta (min)	Delta %
Baseline Case	Houston	2.60	0.69	1.91	73%
	Chicago	2.81	0.76	2.05	73%
	Duluth	2.58	0.72	1.87	72%
1. Wall and Roof Insulation to Equipment Efficiency	Houston	2.59	0.69	1.90	73%
	Chicago	2.60	0.71	1.90	73%
	Duluth	2.83	0.77	2.06	73%
2. Wall and Roof Insulation to Window Type	Houston	2.61	0.69	1.92	73%
	Chicago	2.62	0.71	1.91	73%
	Duluth	2.75	0.75	2.00	73%
3. Wall and Roof Insulation to LPD	Houston	2.59	0.70	1.89	73%
	Chicago	2.64	0.71	1.93	73%
	Duluth	2.84	0.77	2.07	73%
4. Window type to Equipment Efficiency	Houston	2.59	0.70	1.89	73%
	Chicago	2.65	0.71	1.94	73%
	Duluth	2.02	0.76	1.26	62%
5. Window type to LPD	Houston	2.60	0.70	1.90	73%
	Chicago	2.67	0.71	1.96	73%
	Duluth	2.82	0.76	2.05	73%
6. LPD to Equipment Efficiency	Houston	2.58	0.70	1.88	73%
	Chicago	2.61	0.73	1.88	72%
	Duluth	2.81	0.76	2.05	73%
Average		**2.63**	**0.72**	**1.91**	**72%**

Table 27 below shows the run times of the annual and QuickSim simulations for the Primary School prototype. The Primary School prototype takes the longest to run for the three building types. The average runtime for the annual run is 6.86 minutes, while that for the QuickSim run is 1.42 minutes. On an average, this represents a reduction in runtime by 79% or a saving of 5.44 minutes per run.

The average reduction in runtime across all the three building types is about 75%. Under an environment where batch runs of simulations are executed the total runtime reductions could be that much more valuable.

Table 27: Primary School runtime comparison

Case/Trade-off Description	Location	Runtime			
		Annual (min)	QuickSim (min)	Delta (min)	Delta %
Baseline Case	Houston	6.79	1.38	5.40	80%
	Chicago	6.84	1.44	5.40	79%
	Duluth	6.81	1.42	5.40	79%
1. Wall and Roof Insulation to Equipment Efficiency	Houston	6.77	1.38	5.39	80%
	Chicago	6.90	1.45	5.45	79%
	Duluth	6.84	1.43	5.42	79%
2. Wall and Roof Insulation to Window Type	Houston	6.80	1.38	5.42	80%
	Chicago	6.91	1.44	5.47	79%
	Duluth	6.71	1.42	5.28	79%
3. Wall and Roof Insulation to LPD	Houston	6.73	1.38	5.35	80%
	Chicago	6.89	1.44	5.45	79%
	Duluth	6.81	1.43	5.38	79%
4. Window type to Equipment Efficiency	Houston	6.83	1.38	5.45	80%
	Chicago	7.06	1.46	5.61	79%
	Duluth	6.96	1.43	5.53	79%
5. Window type to LPD	Houston	6.79	1.39	5.40	80%
	Chicago	7.03	1.45	5.57	79%
	Duluth	7.02	1.43	5.59	80%
6. LPD to Equipment Efficiency	Houston	6.81	1.39	5.43	80%
	Chicago	6.91	1.43	5.47	79%
	Duluth	6.89	1.45	5.45	79%
Average		**6.86**	**1.42**	**5.44**	**79%**

5.0 Discussion of Results

The analysis from the three tests shows promising results. These results are discussed below.

1. **Trade-off Comparison:** The trade-off comparison captures the result of the pass-fail test commonly used in energy code compliance. Section 3.4.1 describes the test setup for the trade-off comparison, and the analysis is presented in Section 4.1. The absolute difference between compliance indices between the QuickSim method and the annual simulation was less than 1.0% for 125 of the 126 simulation cases. The average delta between the compliance indices was 0.2%, 0.2% and 0.4% for the Retail Strip Mall, Medium Office and Primary School prototypes respectively. For the Retail Strip Mall and Medium Office prototypes, all the cases have a compliance index delta less than 0.5%. In the Primary School prototype, 88% of the cases have a compliance delta less than 0.5%.

2. **Sensitivity Analysis:** A sensitivity analysis was performed on the QuickSim method to determine how well its response correlates to that of the annual simulation when building component levels are changed. Section 3.4.2 describes the test setup, and the analysis is presented in Section 4.2.

   In the sensitivity analysis, the maximum variation between compliance indices of QuickSim and annual simulation occurs at the two extremes of component levels, i.e., at -30% and 30%. These component levels represent the maximum change in component values, such as insulation or LPD compared to the baseline. The average delta between the compliance indices was 0.3%, 0.2% and 0.3% for the Retail Strip Mall, Medium Office, and Primary School prototypes, respectively. These average differences in compliance indices are across 108 simulation runs per building type. For the Retail Strip Mall and Medium Office prototypes, more than 95% of the cases have a compliance index delta within 0.5%. For the Primary school prototype, 86% of the cases have a delta within 0.5%. Two cases in the primary school prototype show a compliance index delta of greater than 1.0%. For both these cases, the compliance index swings over 10% of the baseline.

   The trend graphs show the change in compliance index with a change in component level for the QuickSim and annual simulation cases. In all the cases, the QuickSim method is able to closely follow the trend of the annual simulation. It is also insensitive to climate location. For the two Primary School cases mentioned above, where the compliance index delta rises above 1.0%, the QuickSim trend can be seen to deviate slightly from the annual trend.

3. **Runtime Comparison:** The run time comparison showed that the QuickSim method can reduce EnergyPlus runtimes by one-third. All the 126 cases from the trade-off comparison were run on a local Windows computer to determine the runtimes using QuickSim. The average reduction in runtime for the Retail Strip Mall, Medium Office and Primary School prototypes were 75%, 72% and 79%, respectively. These reductions are equal to an average savings of 1.92, 1.91 and 5.44 minutes for the three building types. The Primary School building type requires the longest runtime for the annual run, so the absolute saving in runtime is also higher than the other building types.

4. **Choice of weeks for QuickSim:** The trade-off comparison and sensitivity analysis provided strong evidence that the QuickSim method is indeed able to correctly predict compliance indices for the building types that were tested. The 4 weeks selected for the QuickSim run period were arbitrarily

chosen and yet, were able to produce accurate results. Another test was run to determine if a different, but similar quartet of weeks would yield results that matched those of the previous selection. The new set of 4 weeks was selected such that, each of the weeks is offset by 4 weeks from the earlier selection. This method yields the following 4 weeks: 8, 21, 34, 47. The Medium Office building type was chosen for this test. Trade-off comparison cases 1 and 6 were run for all the climate locations for the Medium Office building type. The results from this analysis are presented in Table 28.

Table 28: Medium Office trade-off comparison using alternate subset of weeks for QuickSim

Case/Trade-off Description	Location	EUI		Compliance Index		% Delta
		Annual	QuickSim	Annual	QuickSim	
Baseline: Standard 90.1 2004						
Standard 90.1-2004 minimally code compliant building	Houston	46.84	3.59	-	-	-
	Chicago	49.71	3.80	-	-	-
	Duluth	55.76	4.39	-	-	-
1. Wall and Roof Insulation to Equipment Efficiency						
Wall and roof insulation reduced by 10% from baseline and equipment efficiency increased to 90.1-2010 standard.	Houston	45.35	3.46	3.2%	3.7%	**-0.6%**
	Chicago	49.18	3.75	1.1%	1.3%	**-0.2%**
	Duluth	55.97	4.42	-0.4%	-0.7%	**0.3%**
6. LPD to Equipment Efficiency						
Lighting power density increased by 10% from baseline and equipment efficiency increased to 90.1-2010 standard.	Houston	46.26	3.53	1.2%	1.8%	**-0.5%**
	Chicago	49.63	3.79	0.2%	0.4%	**-0.2%**
	Duluth	56.19	4.43	-0.8%	-0.8%	**0.1%**

The results show that the alternate set of weeks does not result in any abnormal compliance indices. The delta between the annual and QuickSim indices is well within the 1.0% limit.

6.0 Conclusions

1. The analysis of the QuickSim methodology suggest that QuickSim can reliably be used with EnergyPlus for approximating annual simulation results while significantly reducing simulation runtimes. The compliance index variation between an annual simulation and a QuickSim simulation remains below 1.0% for almost all the cases tested in this study.

2. QuickSim is able to respond in the same manner as an annual simulation to changes in building components. The variation of weather conditions occurring in 1 year appears to be captured by the 4 week run period. The insensitivity of QuickSim to building types or climate locations tested in this study implies that it may be used for other building types and climate locations.

3. For compliance indices greater than 10%, deviation of greater than normal was observed for the QuickSim cases. Even in these cases, the variation was only slightly higher than the acceptable margin.

4. The simulation runtime can be reduced by one third by applying the QuickSim method. The saving in runtime is greater when the building model requires a longer time to run.

5. This study investigates the accuracy of QuickSim method in predicting compliance indices for energy code compliance. The tests do not imply that the method can be applied to determine absolute building energy consumption for other applications

7.0 Bibliography

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