

# COMPARING BUILDING PERFORMANCE TRENDS IN THREE ENERGY SIMULATION PROGRAMS

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## ABSTRACT

Retrofitting a building can improve energy efficiency. To predict a building's future performance, it is important to calibrate the energy model to the existing energy consumption as the basis for design changes. This type of calibration often requires detailed hourly energy models that result from extensive data collection and audits. Yet, even with the best of intentions and paying attention to geometry, materials, occupancy, lighting, heating and cooling schedules, and specific climate data, there is often a disconnect between the simulation results of digital models and the energy use of real buildings. In this study, actual monthly electricity results were compared against results in eQuest, DesignBuilder and Vasari. Then four energy conservation measures, focusing on the building envelope, were simulated for three different climate conditions in California. The intent was to determine if the retrofit options in all these programs produced similar trends (up/down) in the results of the simulations.

## 1. INTRODUCTION

Buildings are responsible for almost half of the energy used in the U.S. (1). Some important challenges affecting existing buildings, such as the Architecture 2030 Initiative adopted by AIA and the Net Zero Energy Initiative for Commercial Buildings by the Energy Independence and Security Act from 2007, encourage energy reductions to achieve net zero consumption. Moreover, over 630 colleges adopted the American College and University Presidents' Climate Commitment for developing plans for climate neutrality (2).

There are about 360,000 institutional buildings in the US (3). The Von KleinSmid Center (VKC) at University of

Southern California is one example. Built in 1966, the 95,287 sq. ft. (8,852 m<sup>2</sup>) floor area is distributed in three stories of classrooms and offices with a basement dedicated to a library (Fig. 1).



Fig. 1. Von KleinSmid Center

The actual energy consumption of VKC in 2010 was reported as 80 Kbtu/sf. This was compared with the energy consumption data benchmarks for commercial buildings available at the Commercial Building Energy Consumption Survey (CBECS), which provides benchmarks for existing buildings. For educational buildings, the CBECS defines an average EUI (energy use intensity) of 88.3 Kbtu/sf (4). Overall, VKC is performing well compared to others surveyed, but it is still under consideration for upgrades to further improve its performance.

Comprehensive building retrofits frequently require calibrated hourly energy models. In order to predict the

effectiveness of different retrofit strategies, a computer model was created calibrated to actual energy consumption of VKC. This calibration is a necessary initial step towards the task of obtaining a close representation of the current building behavior within acceptable error ranges. Statistical methods are then used in the identification of error margins, such as the coefficient of variation of the root mean square error (CVRMSE) and the Normalized Mean Bias Error (NMBE) (5). These error values are compared with standards such as ASHRAE 14, International Performance Measurement and Verification Protocol (IPMVP), and Federal Energy Management Program (FEMP) (6).

TABLE 1. TOLERANCES FOR CVRMSE AND NMBE (7)

	ASHRAE 14	FEMP	IPMVP
$CVRMSE_{Month}$	±5%	±5%	±10%
$NMBE_{Month}$	±15%	±20%	±15%
$CVRMSE_{Hour}$	±10%	-	-
$NMBE_{Hour}$	±30%	-	-

The energy modeling was completed in DesignBuilder 3.0.0.105, eQuest 3.64, and Project Vasari (Beta 2). DesignBuilder uses EnergyPlus as underlying engine, whereas eQuest and Vasari uses DOE-2.2. DesignBuilder and eQuest are widely used by energy consultants because they include the ability to input complex sets of data for hourly energy simulation. In contrast, Vasari is used for whole building conceptual energy analysis. The energy model is uploaded to the Green Building Studio cloud where the calculations are done using DOE-2 engine.

## 2. MODELING METHODOLOGY FOR CALIBRATION

VKC was modeled in the three programs. It was modeled as closely as possible according to the original drawings with same weather information and thermal zones. VKC building's tower (Fig.1) has been omitted from the models because it is an unconditioned and unoccupied zone of the building.

One challenge in the geometric construction of the model was in creating the underground central courtyard of the building. In DesignBuilder the “attachment” properties of the wall could be used to adjust adjacency from “ground” to “exterior wall,” which allowed the incorporation of glass in the courtyard. However, that capability does not exist in eQuest and Vasari, so a different approach had to be taken. In the eQuest model the central courtyard was not possible to construct from independent geometry. Therefore, the geometry had to be drawn in a continuous polyline, which created a gap that is not present in the existing building.

Unfortunately, with the absence of any attachment property, the energy model filled the central void with soil. Due to these problems, the model was lifted up, and the basement was recreated giving the perimeter walls (attached to the ground) a higher thermal resistance.

In Vasari the underground courtyard proved difficult again; glazing could not be added to any part of the model beneath the ground plane. To get around this issue the ground plane was lowered to the basement level and all context building were raised to match the appropriate faux ground level. A ground mass was build around the model to simulate dirt. All three models are shown in Figure 2.

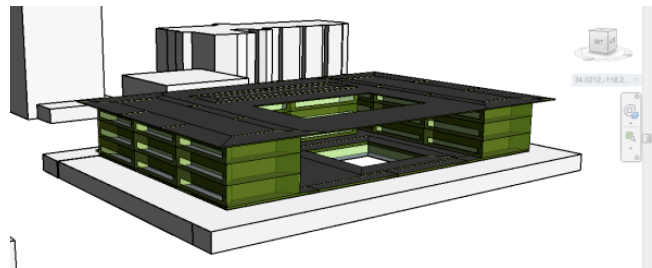
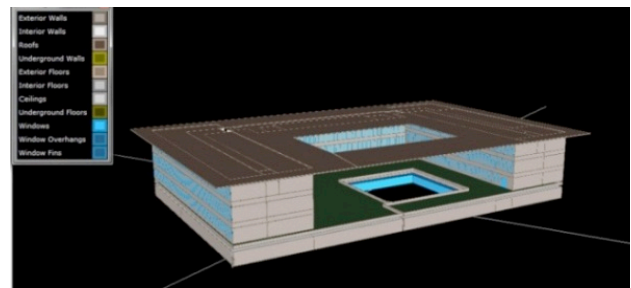
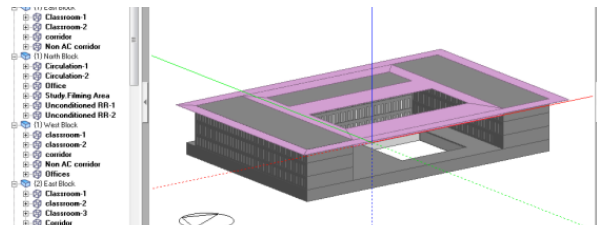


Fig. 2. Models of the building in DesignBuilder, eQuest and Vasari

DesignBuilder uses the concept of “blocks” that represent different thermal zones, eQuest uses the concept of “shells” that also contain different thermal zones, and Vasari is based on the concept of “a solid mass” where each floor was used to separate the mass into different thermal zones. Windows were individually placed in the models to match the exact ratio.

Actual hourly weather data was used for the period of analysis and location in DesignBuilder and eQuest. However, a user can not customize this same weather dataset for the exact same time period in Vasari. Instead the data contained in the software from the closest weather station was used. Vasari reported one weather station was 5.6 miles away, different from the one reported by GBS from 4.7 miles, and might introduce some minor differences in the results. Characteristics of VKC such as occupancy schedules, material definitions, and HVAC configuration were duplicated according as close as possible in each of the three software programs. The problems of calibration and final results were explored in a previous study for this building (8). Vasari presented different problems by having a more limited set of options of only 40 conceptual constructions and 11 types of HVAC systems.

### 3. RESULTS OF MODEL CALIBRATIONS

In annual electricity use, the three models were consistent. DesignBuilder was 15% and Vasari was 3% lower, while eQuest was 1% higher compared to the actual data. However, higher differences appeared between real and predicted data for fuel use. While Vasari over-predicted, eQuest and DesignBuilder models not only under-predicted the building performance, but the monthly profiles varied widely from VKC's reported consumption. The Vasari model resulted in 30% over, while DesignBuilder and eQuest were 88% and 70% under the actual value, respectively. The original gas data may have had errors; this was noted earlier in a previous paper (8).

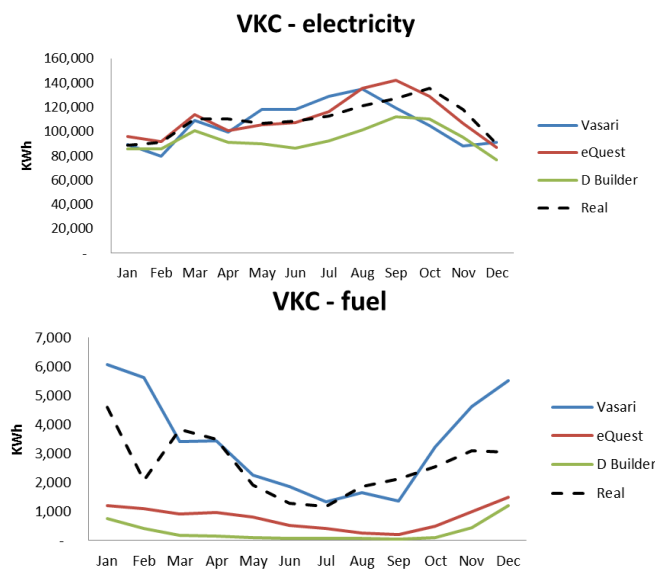


Fig. 3. Comparison of actual data with eQuest, DesignBuilder, and Vasari results

The ASHRAE 14 guidelines ( $\pm 15\%$  for CVMSE and  $\pm 5\%$  for NMBE) were followed as acceptable tolerance for monthly data (7). In electricity, the eQuest and the Vasari models were within the range, while DesignBuilder was slightly off. The gas simulation values cannot be considered calibrated with the actual data due to erroneous utility data. Specially Vasari gas results were way off, but no further possibilities of adjusting heating equipment, such as annual fuel utilization efficiency, was possible. Hence they will not be considered further in this study.

TABLE 2. COEFFICIENT OF VARIATION OF THE ROOT MEAN SQUARE ERROR (CVRMSE) AND THE NORMALIZED MEAN BIAS ERROR (NMBE) FOR VKC

ELECTRICITY	CMRMSE	NMBE
DesignBuilder	16.5	15.8
eQuest	7.8	-1.0
Vasari	14.6	-3.1

FUEL	CMRMSE	NMBE
DesignBuilder	78.0	69.4
eQuest	79.9	76.1
Vasari	58.3	-32.75

### 4. CLIMATE ZONES

The model simulations were run in two other climate zones in California with dissimilar characteristics: CZ01 (Eureka) with cool wet winters and cool summers and CZ014 (Barstow) for hot, dry summers and cool nights (10). For these two additional conditions, eQuest used the Vasari weather file (taken from Green Building Studio .bin weather files) while DesignBuilder used the .epw weather data contained within the software.

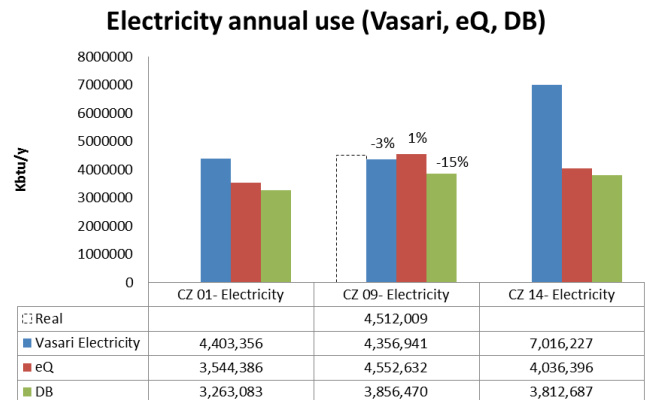


Fig. 4. Simulated annual electricity use in three climate zones.

The eQuest values match most closely in CZ 09 and are always higher than Design Builder predictions in the other climate zones. Note that in CZ 01 and CZ 14, without the actual consumption value, only the relative usage was determined, not the percentage deviation: Vasari highest, then eQuest, then DesignBuilder.

## 5. RETROFIT STRATEGIES FOR BUILDING ENVELOPE

The main objective of this study was to observe the changes in energy consumption by applying the same retrofit strategies (energy conservation measures for the façade including insulation, glass replacement, and shades) in the three software programs. The specific values were not considered as important as the trend of consumption. For example, if one of the software programs predicted that more insulation would decrease energy consumption, than it was compared with the other two software programs to see if they also predicted a savings.

The first step in the preparation of the models for simulating the strategies was testing the incorporation of daylighting controls to the models. Although this worked for eQuest and DesignBuilder, it did not in Vasari. Vasari model was opened in Green Building Studio, were few attempts led to failure in the VKC model. Further exploration might it possible to overcome the internal error generated in VKC model daylighting controls incompatibility. The simulations were done with no daylighting controls.

A set of four strategies for retrofitting the envelope were modeled: high wall insulation, high roof insulation, high performance glass, and sunshades. Because Vasari had fewer choices than DesignBuilder and eQuest, it dictated the selection set of parameters and what values they could be set to. Table 3 describes the values that were input into the three software programs.

**TABLE 3. BASELINE AND SINGLE OPTION INPUTS FOR RETROFITTING IN THE THREE SOFTWARE PROGRAMS**

	VASARI	EQUEST	D BUILDER
ERM-1. High Mass Construction- High Insulation	R-value: 17 (Sf- hr/Btu) Unit Density: 115 (Lbm/sf) Heat Cap: 23 (Btu/sfF)	6" concrete + 0.2' polyurethane R-value= 17	R-value of 17

	VASARI	EQUEST	D BUILDER
ERM-2. High insulation- Cool roof	R-value: 33.3(Sf- hr/Btu) Unit Density: 12 (Lbm/sf) Heat Cap: 3 (Btu/sfF)	Existing wall + Foam polyurethane, 5" R-value= 33	R-value of 33
ERM-3. Double pane clear no coating	Glazing: Double Pane Clear- U-value: 0.29 SHGC: 0.27 Tvis: 0.64	Glazing customized definition: U-value: 0.33 SHGC: 0.29 Tvis: 0.64	Glazing customized definition: U-value: 0.29 SHGC: 0.27 Tvis: 0.64
ERM-4. Sunshades	3' overhangs	3' overhang in steel	3' overhang in steel

In general, savings or increments on electricity use were small in most of the predictions, and the trends were not always consistent.

In CZ 09, the trends agreed for two of the cases: wall insulation and double glass. Vasari's results disagreed with eQuest and DesignBuilder for roof insulation. eQuest prediction for sunshades disagreed with Vasari and DesignBuilder. In addition, Figure 4 showed that DesignBuilder tends to have a lower energy use than the other software programs for the three climate zones; in Figure 5, its savings are generally higher. There is a complete shift from what would be expected. After resulting in lower annual electricity consumption, it showed the higher savings.

In CZ 01, the trends disagreed for all cases. The highest disagreement is found for the wall insulation, where Vasari showed an important saving while the others showed very small increases and decreases. Different behaviors are shown in DesignBuilder and eQuest. The DesignBuilder model showed savings for all strategies, whereas eQuest model resulted in slight increments for all of them.

As illustrated earlier in Figure 4, Vasari showed the biggest difference in annual use for electricity in CZ 14. It again showed trend differences for the wall insulation and roof insulation. The only agreement among the three programs is in double pane glass for this climate.

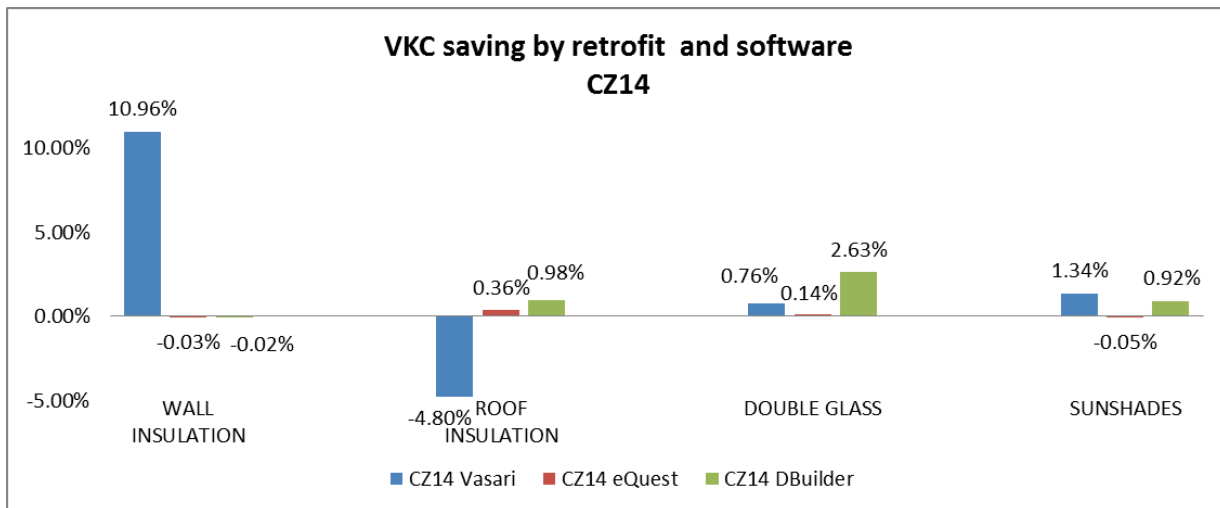
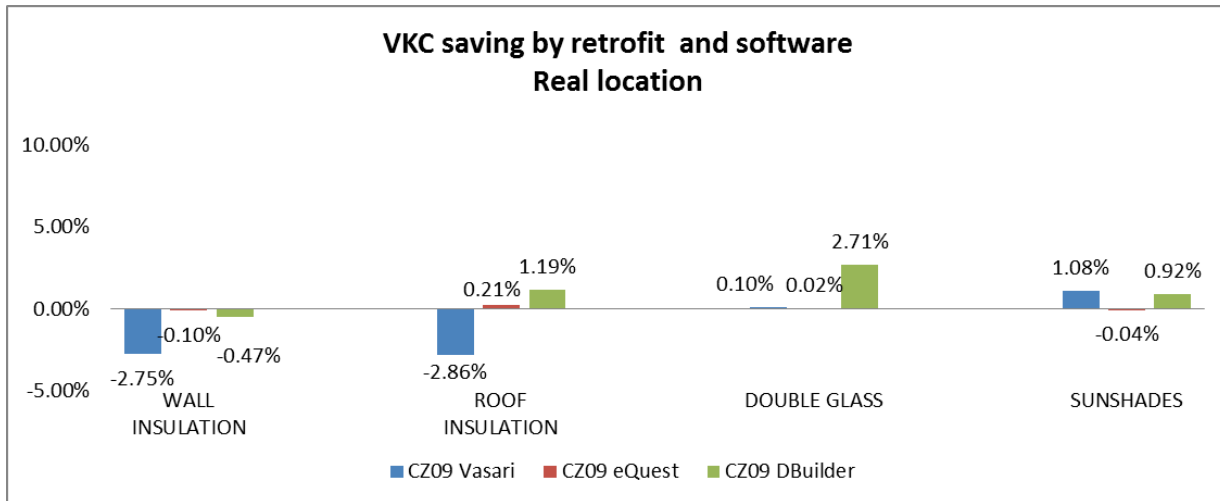
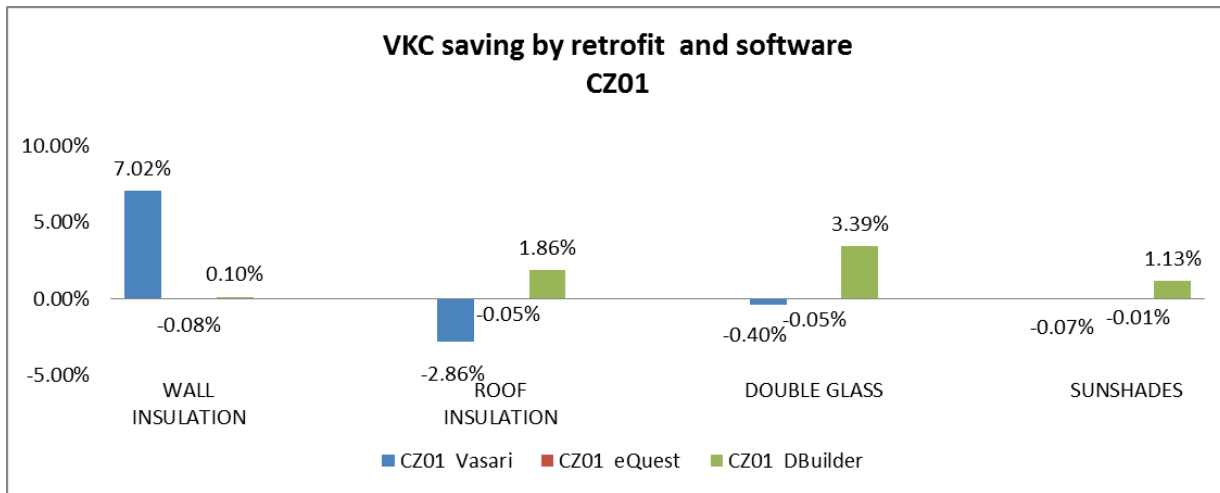


Fig. 5. Comparison of savings in electricity for 3 software programs, 4 scenarios, and 3 climate zones



## 6. SECOND TEST

As the buildings did not seem to be trending consistently compared with each other, a less complex example was examined. A hypothetical 3-story, 100 by 100 sq. ft. office building was modeled to observe if the trends on its behavior matched those of VKC. Given the more limited range of options, the Vasari model was used as reference to set the parameters.

The Vasari model was exported as a DOE2 (.inp) to eQuest and as gbXML (.xml) to DesignBuilder. The DOE2 .inp file was examined to learn the values of the parameters that were not detailed in Vasari such as schedules for equipment, occupancy, lighting, infiltration set-points, and set-backs for heating and cooling controls. Once in eQuest, the .inp file was opened in the detail mode.

DesignBuilder was able to import the gbXML file, but only the geometry transferred. Information about occupancy, schedules, and equipment (from the DOE2 inp file) were set in DesignBuilder.

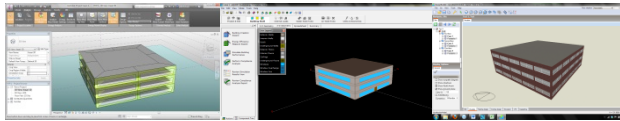


Fig 6. Models for theoretical office building in the three software programs

Weather data was extracted from Green Building Studio to minimize differences and saved as a .bin and a .csv format to be used in eQuest and DesignBuilder respectively. The .bin file was used in eQuest. However, special care was needed to fix some of the values for the cooling design days and heating design days that were not automatically updated by the weather files in eQuest. The .csv format could be used to create a new EnergyPlus weather file, but this option was not explored in this study, but highly recommended for further studies including calibration. Instead, the weather file contained in DesignBuilder was used for the same weather station.

Even though the base model was exported to the other software programs and the best match for weather file was used, the models fell within calibrated range for electricity, but not for fuel. Despite the profiles' similarity, no explanation was found for such difference (Fig. 7 and Table 4), and the fuel values will not be used for the next part of the study.

The electricity results of eQuest and DesignBuilder models were close to Vasari and within calibration margins for CZ09. EQuest also closely matched electricity with less than 2% in CVRMSE and NMBE. "calibrated" range.

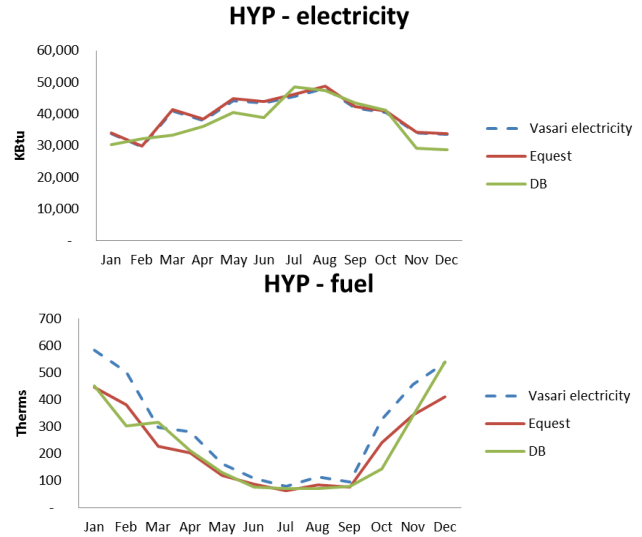


Fig. 7. eQuest and DesignBuilder models compared to the Vasari reference model.

TABLE 4. COEFFICIENT OF VARIATION OF THE ROOT MEAN SQUARE ERROR (CVRMSE) AND THE NORMALIZED MEAN BIAS ERROR (NMBE).

Electricity	CVRMSE	NMBE
DesignBuilder	10.04	5.57
eQuest	1.17	-1.18
Fuel	CVRMSE	NMBE
DesignBuilder	34.24	24.79
eQuest	29.53	26.28

Results are shown for all three climate zones (Fig.8).

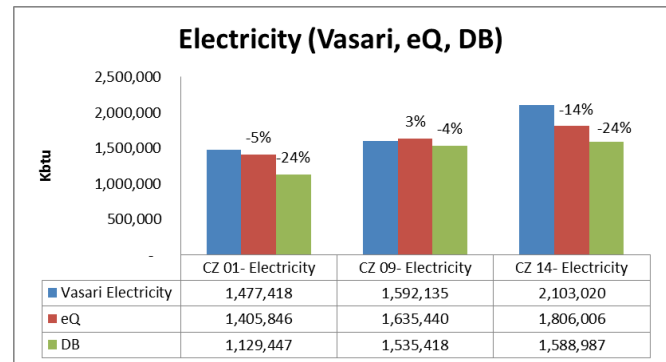


Fig. 8. Electricity use in the three models for three climate zones

The same four strategies were measured in this test (high wall insulation, high roof insulation, high performance glass, and overhangs). In this case, the values were of a higher magnitude than VKC which made it easier to discern the trends.

Generally the trends matched better between each software tool for this case study.

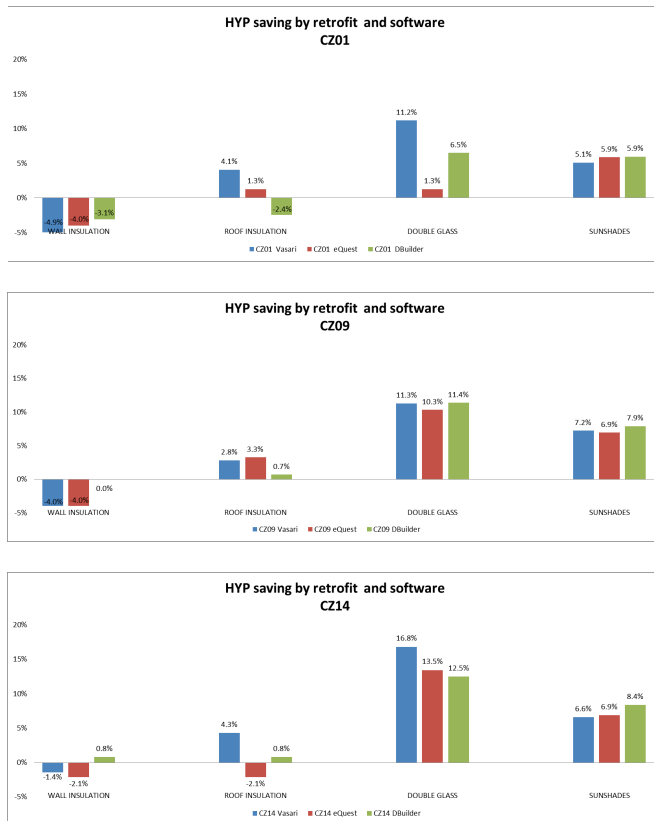


Fig. 9. Comparison of savings in electricity of three software programs for three different climates (hypothetical building).

## 7. DISCUSSION

Several issues came up during the study using VKC. The most important of which was whether or not the same building characteristics were actually being simulated in the three software programs. Vasari was used as the default case because it had the fewest options and those could be matched in eQuest and DesignBuilder. However, some assumptions that the software made were difficult to discover. For example, the occupancy using initial data resulted in a total of 98 people in the building. This did not match the amount of people given by Vasari analysis report, which indicated 124 people. Some of those default values could be found in the Autodesk Wiki help site. Learning more about .inp files helped bring to light other inconsistencies. For example, in eQuest, the glass definition in the input file was different than the glass contained in the DOE2 library. VKC ended up being a poor choice for this study as it was difficult to improve its performance much by the strategies that were chosen.

The second study, by being more limited, lead to a higher degree of confidence that building characteristics matched. The input file was used in eQuest, whereas the geometry in DesignBuilder was completed with manual inputs within the software. Despite that effort and the match of weather files, total match within calibrated ranges were not achieved across all software programs and climates.

It was not expected that the results would exactly match between the software programs. There are numerous sources that could lead to these divergences: user error, weather files, mismatched parameters (because the exact ones don't exist between all the programs), etc. One source of discrepancy is in the calculation methodologies used by the software programs. DesignBuilder works based on a thermal balance method, which considers elements in the model as independent surface. On the other hand, eQuest and Vasari work using a weighting factor method. DOE-2 assumes that heat transfer, air convection, solar gains are independent, which are approximated as linear processes. Those are finally added together to obtain total loads in the building (11). However, the exact values were not considered critical, only the trends.

Further studies could be done, one with more experienced users and another with lots of students. More experienced users would help increase the confidence level that the results are accurate, but not all users are capable at that level. It would be interesting to have lots of students run a simulation in one software program, for one building, in one climate zone, and then compare the results. Then try the other two software programs.

## 8. CONCLUSION

It is crucial that architects, consultants, and owners are able to trust the simulations of energy models for accurate predictions of energy usage within standard error ranges. However, in the early design stages the exact numbers might not be critical. The designer is often just looking at the trends – for example, is energy saved by increasing the amount of windows? The choice of software should not change the predicted energy consumption direction.

Yet, the results of this study were mixed. It was hypothesized that the up/down trends in the results would be consistent across the software programs. It was disappointing that clear conclusions for the study cannot be made even though the simulations were run by fairly knowledgeable students. It is becoming apparent that “quick and easy” energy studies might not be very useful in some cases.

The conclusion of this study is not that certain programs are accurate or inaccurate, but that even with reasonable care, results are not always predictable with regards to the trend of energy savings for these three programs.

## 9. ACKNOWLEDGMENTS

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