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IMPACT OF MODELER DECISIONS ON SIMULATION RESULTS

Pamela Berkeley[1], Philip Haves[2], and Erik Kolderup[3]
[1]University of California Berkeley, Berkeley, CA
[2]Lawrence Berkeley National Labs, Berkeley, CA
[3]Kolderup Consulting, San Francisco, CA

ABSTRACT

The user generating the model for Building Energy Simulation programs is responsible for a variety of decisions that affect simulation results. A study was conducted to determine the magnitude and nature of the modelers role in simulation results. 12 professional energy modelers were given identical plans for a commercial building and instructed to complete a model of the building in eQUEST. Results for total yearly electrical consumption varied by -11% to $+104\%$ and results for gas consumption varied by -61% to $+1535\%$. A one at a time factor analysis was performed on the participant modeling decisions with a baseline model created from modeling best practices. The results of this analysis indicate that decisions related to equipment power levels caused the most variation in electricity predictions, while HVAC decisions caused the greatest deviation from the baseline model predictions for both gas and electricity consumption. Future work should investigate a broad range of buildings and modelers and additionally explore the possibility of reducing modeler variation by modifying simulation program user interfaces.

INTRODUCTION

Modelers are responsible for interpreting building information and plans into models that yield energy predictions. As such, they play a critical role in the variability and reliability of energy predictions. However, most research into the variability of energy predictions overlooks the role of the modeler in producing simulation results.

Previous studies conducted on the variability caused by modelers indicate that modeling programs allow both novice and expert users to make diverse input decisions for the same modeling scenario. Bloomfield (1986) described the sensitivity of a model of a residential building common in the UK to various modeling decisions, and outlined the primary opportunities for modeler variability in simulation programs at the time. Guyon (1997) provided a group of modelers with identical plans to an existing French residential building and had them use the same program (CLIM2000) to determine energy use predictions for the heating months of the year (Oct. 1 through May 21). It was found that energy predictions varied -41% to $+39\%$ between modelers as compared to a reference model created by an expert user. Modelers in this study had a range of backgrounds and no mention was made of a time limit for the completion of the model. Ibarra and Reinhart (2009) explored the results of novice daylighting modelers who were tasked with measuring and modeling an existing L-shaped classroom. Student results were compared against a best practices model created by the authors, and the majority were found to over-predict the average daylight factor by 200% to 400%. In another study (Bradley, Kummert, and McDowell 2004), the authors each generated their own models for two different BESTEST procedures and compared their results. Despite the simple nature of the BESTEST base case scenario, the modelers' assumptions caused at least a 20% difference in yearly cooling energy predictions, although many of their results fell within the acceptable range defined by BESTEST.

All of these studies revealed variation between the results of modelers when presented with identical building plans, but none of them studied professional energy modelers and commercial buildings. Furthermore, sensitivity analyses of modeling decisions have not been performed on results generated by a test sample of modelers. Additional research in this area would better define the effect of individual modeling decisions, inform the simulation community on the expectations of consistency in simulation results and reveal best practices for modelers to reduce unnecessary variability between modelers.

MODELER STUDY

The experiment was designed to place professional energy modelers under conditions that replicated those experienced during a typical modeling project. By providing all modelers with identical plans and building information it was possible to assess the effects of typical modeling pressures and of the individual modeler on energy modeling results.

Participant recruitment and demographics

Participants were recruited for the study from the email lists of the Pacific Energy Center, and the San Francisco chapters of IBPSA and ASHRAE. They were required to be familiar with eQUEST and to bring a laptop to the study. In order to encourage modelers to participate, they were provided with a meal and educational speaker sessions. There was also a drawing for the book, Building Performance Simulation for Design and Operation, and a year subscription for the Journal of Building Performance Simulation.

Twelve professional energy modelers participated in the study. A demographic survey of the participants yielded the information presented in Table 1. All twelve participants had at least a bachelor's degree, some Mechanical Engineering background and typically modeled commercial buildings.

Table 1: Results of the demographic survey of the 12 participants.

Category	**Responses**
Master's degree	5 participants
Experience in BES Field	0.5 to 15 years
Experience with eQUEST	0.5 to 9 years
Received eQuest training	8 participants
Experience with other BES programs	0 to 5 other programs
Experience other than Mechanical Engineering	6 participants

Description of building used in study

The building used in the study needed to be complicated enough that modelers would be required to prioritize modeling decisions, but simple enough that they could complete the study in the allotted time period. It was also determined that a building located in the climate local to the participating modeling community would yield results that best demonstrated how modelers behave in their typical work environment. It was decided that plans that fit the above description were those for a school administrative building located in the San Jose, CA climate zone. The single-story building plans were complicated by a vaulted lobby area and an irregular floor plan and two overhangs (Figure 1). Four packaged single zone (PSZ) HVAC units were included in the mechanical plans, as well as 2 split system HVAC units and 4 exhaust fans. Plans indicated the location of a domestic water heater, but no equipment information was included. Lighting plans indicated both interior and exterior lights.

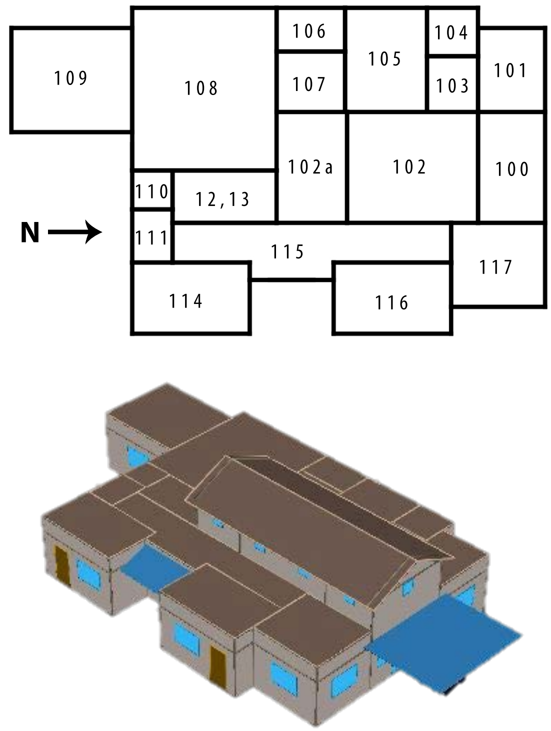


Figure 1: A simplification of the building floor plan used in the study (top) and the 3D representation of the building from the eQUEST model (bottom). The outer dimensions of the building are 49 ft *by 80* ft*. Descriptions of the rooms are included in Table 2.*

Table 2: Descriptions of rooms. In most cases, these are the labels from the architectural drawings.

Room num.	**Description**
100	Lobby (open to 102 and 115)
101	Office
102	Reception (open to 100 and 115)
102a	Reception area past dividing wall
103	Record storage
104	Toilet (accessed through 105)
105	Nurse
106	Electrical (outside access only)
107	Data
108	Staff lounge
109	Workroom
110	Riser
111	Custodian
112,113	Toilets
114	Multi-use office
115	Foyer (open to 102 and 100)
116	Principal
117	Conference

Information given to participants

Before the study began, modelers were told that they had three hours to complete a model of the building in eQUEST and to turn in simulation results. They were also requested to fill out the demographic survey (the results of which were presented in Table 1).

Participants were provided with the information they would typically receive for a modeling job:

- architectural drawings
- mechanical plans
- mechanical schedule
- lighting plans
- lighting schedule

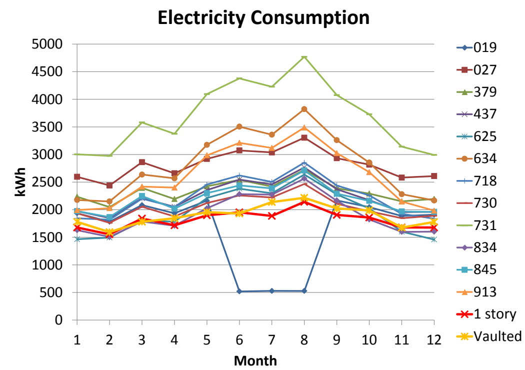
The one piece of information that was omitted from the above plans was the title of the project, as required by the architectural firm that supplied the plans. Participants were told the building was located in the local California Climate Zone 4 (CZ04).

Participants were instructed verbally and in print: "An important part of this exercise will be how you budget your time on the simulation task. Direct the most attention towards the areas on the simulation you believe are the most important if you are running short on time. If you feel like you need additional information at any point, don't hesitate to ask." Additional information beyond the plans and climate zone, such as building type and applicable building code values, was available to participants in the event that they would request this information.

Study results

All participants completed a simulation by the end of the study. Three digit numbers had been assigned to each participant and simulation files were submitted digitally into folders labeled with the respective participant number. The participant results in Figure 2 were presented at the conclusion of the study event and a discussion followed.

As discussed at the study event and as is immediately apparent from the electricity use plot, only one participant deduced that the building was a school building and would therefore have reduced use during summer months (nobody requested information on the building type, however). Another participant noted that despite greatly simplifying the building geometry, this participant's model results fell within the clustered results on both plots. A few participants remarked that they had not remembered to set the climate zone to CZ04; however, the default in eQUEST was CZ04 and therefore no results



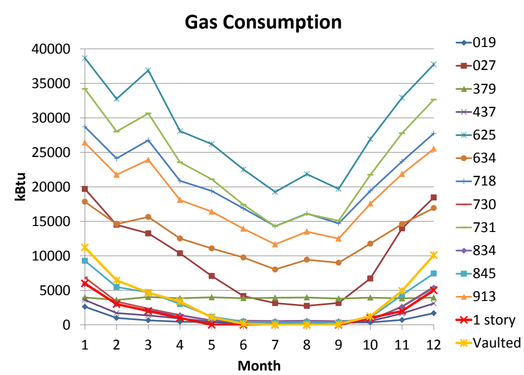


Figure 2: Total monthly electricity and gas predictions for study building. Results labeled with a three digit number pertain to results submitted by participants. The results labeled "Vaulted" indicate the faithful baseline model, while "1 story" indicates the modified baseline model used in the OAT analysis.

were affected by this oversight.

The large difference between participant energy use predictions was not readily explained by any one feature of the models or modeler background. It was therefore necessary to systematically evaluate all participant model decisions. The procedure and results of this analysis are discussed in the following section.

ANALYSIS OF MODELING DECISIONS

OAT analytical method

One-at-a-time (OAT) analysis is performed by evaluating a model for each possible input across each factor being investigated. The average and the standard error of measurement of the results for each factor then provide a characterization of the effect of the inputs on simulation results. For this study, a best-practices model was used as a baseline into which participant decisions were substituted. Basic decision categories (factors) were chosen to expose the variation in participant inputs but also to interface successfully with the baseline model.

Baseline model

The baseline model was created to be as faithful to building plans as possible and to conform to California's Title 24 requirements (Title24 2010) or the values recommended in ASHRAE Fundamentals (Ashrae 2013). The building floor plan was imported into eQUEST; ceiling and roof heights and window dimensions and locations were measured off of elevation views. Rooms were modeled as individual spaces, and the spaces were grouped into thermal zones according to the mechanical plans. The HVAC equipment parameters were set to those described by the mechanical schedule. Lighting power was input according to the lighting plans, and equipment power levels were set to those recommended by ASHRAE Fundamentals for office type buildings. Exterior wall and window properties were set to the Title 24 required values. All other information, which was not known from the building plans, were set to the eQUEST defaults or were determined according to the combined experience of the authors. Table 3 provides a summary of inputs that were determined by author experience.

Table 3: Deviations from eQUEST defaults for information not in plans or prescribed by Title 24.

Decision	Reason
Electric water heater	Typical for use case
Customized occupancy, equipment, and lighting schedules	EQUEST defaults did not include weekend use
Latent heat gain per person (LHG) and sensible heat gain per person (SHG) for offices (from ASHRAE Fundamentals) for all spaces	Consistent space type for ease of comparison between modeler decisions
Customized number of people per room	Reflective of room label
Lowered HVAC cooling set point below default	Reflective of typical settings in real buildings

The baseline model needed to be capable of accepting any participant's inputs. For most aspects of the model no modifications to the faithful baseline described above needed to be made to accommodate all inputs. However, the vaulted lobby was not modeled by all participants, and the lack of information on what decisions they would have made for this vaulted lobby meant that it had to be removed from the baseline model. All other components of the model were held constant when the lobby was made to be level with all other rooms in the building. Model predictions for the faithful baseline model and the baseline model with the vaulted lobby removed are displayed in Figure 2.

It is important to note that while the baseline model was created to be as faithful as possible, its primary function was to provide a set of reasonable inputs a) to accompany substituted participant decisions during the OAT analysis, and b) off of which participant decisions could be evaluated.

Factor substitutions

Factors were set to be groupings of inputs that reflect distinct decisions made by modelers. Table 4 lists the factors used during the OAT analysis. In most models, these factors involved only a few inputs on the part of the modelers. Some factors, however, potentially involved numerous inputs. Windows properties, lighting power, and HVAC equipment were the principle factors that could have been input piecemeal according to plans or simplified to only require a few inputs. The decision to group multiple inputs into a single factor was also determined by the compatibility of a factor with the baseline model. For example, many of the settings for HVAC equipment determine which other HVAC settings are available for modification. It was therefore necessary to group together HVAC inputs and replace them as a whole.

Geometry-based parameters often required slight modifications in order to be input successfully into the baseline model. As discussed above, the vaulted lobby was removed from the baseline model; for models where the participant included the vaulted lobby, the ceiling heights were set to be the level of all other rooms. The floor plan geometry of the baseline model was not modified for participant inputs; properties of rooms from participant models were put into the corresponding rooms in the baseline model. Some participants had rooms located in positions that did not match the plans precisely, and properties for these rooms were still entered into the relevant room in the baseline model. With very few exceptions, rooms successfully served as the smallest unit of space into which HVAC systems could be grouped for thermal zones. When a room in the baseline model did not exactly match the participant's thermal zoning, the room was placed in the thermal zone that covered the majority of the room. In order to evaluate the effect of all of these geometry approximations, a specific case of the OAT analysis was created where all of a participant's inputs were entered into the baseline model.

Other than modifications made to participant inputs to account for the baseline model's geometry, very few changes were made to the original participant inputs. Occasionally participants had individual building parameter inputs that deviated from the consistent value within a given factor, e.g. a single interior wall had exterior wall properties. In these cases, the inconsistent value was omitted; the impact of these deviations is discussed in the discussion section below. Additionally, it was decided that because modelers were not explicitly told that it was a school building, the school-year schedule was extended into the summer months for the one model that had reduced summer hours.

OAT results

The results of the OAT analysis are shown in Figure 3. The key that links the reference numbers in the plots to the factor descriptions is included in Table 4. Baseline model energy values are the reference line (that is, zero on the y-axis). Positive values indicate that participant decisions, on average, raised the energy use beyond the baseline settings by the height of the bar. Contrariwise, negative values indicate that participant decisions, on average, caused lower energy predictions than the baseline values. The standard error of measurement lines on the plots indicate the region in which the mean of the population of modelers is likely to fall, based on the measurements of the sample and its size.

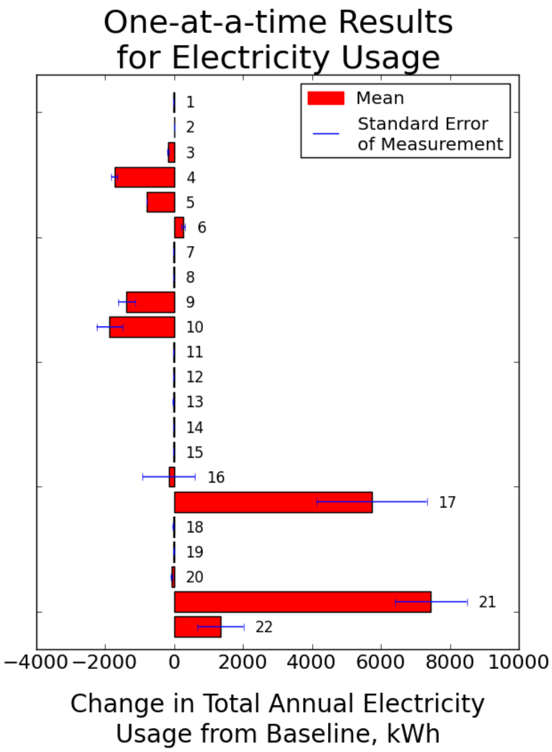
For electricity usage, noticeable deviations from baseline occurred in the following categories: interior wall properties, exterior lights, the water heater, the domestic hot water (DHW) loop, the light and equipment schedules, the lighting and equipment power, the HVAC, and the geometry, with a subtle difference in windows. Gas usage had only very minor differences for most categories, and most of these differences are easily-explained as the opposite effect of properties that increased or decreased cooling demand. The minimal magnitudes of heating energy changes are reasonable for the mild climate that the model was subject to. Only window and HVAC decisions did not fit with the trend of opposing cooling energy differences.

A majority of the noticeable differences in energy use have easily explained sources. Most participants chose U-values for interior walls that far exceeded the U-value used in the baseline model (the mode for the U-value for participants was 2.7 Btu/h–ft^2–F; for the baseline model the U-value was 0.4 Btu/h–ft^2–F). When the interior wall U-values are changed between these two values in a simple core and perimeter zone test model in eQUEST, the magnitude of the change in energy use is similar. The baseline model included exterior lights, but most participant models did not. All participants chose gas water heaters rather than the electric one used in the baseline model, causing a decrease in their electricity predictions and an increase in gas predictions. DHW loop increases seen in participant decisions were caused by higher flow rates. Only one participant set lighting and equipment schedules to have on-hours during the weekends (like the baseline model), resulting in a reduction in average energy predictions when participant schedules were used. Changes in lighting and equipment power directly follow from participant values for these categories. It should be noted that participant decisions for lighting power varied significantly but were still centered around the baseline model values, and by extension, Title 24 requirements. Equipment power for all participants and for the baseline model fell within ASHRAE recommended values. Many participants chose to represent the vaulted lobby in their models, unlike the single story baseline model used for the template file, resulting in an increase in energy use with the original geometry. A contributing factor to the increase in energy predictions with participant geometry were differences in the building floor plan rooms being grouped into spaces in various patterns.

Window and HVAC decisions were the only areas where participant values changed both gas and electricity use, and in these cases heating and cooling energy, in the same direction. Participant values for windows decreased both the cooling and heating energy used, albeit slightly. The primary difference in modeler and baseline decisions in this case were the amount of the exterior wall taken up by windows. Half of the participants had significantly fewer windows than the baseline case, and a quarter of them had the same amount. Participant settings for the HVAC systems dramatically increased the gas and electricity use. Decisions for HVAC systems were not interchangeable between models and OAT analysis could therefore not be applied to HVAC detailed settings to expose specific reasons for energy differences resulting from HVAC systems. A future experimental setup could restrict participant decisions in such a way as to allow the exploration of the underlying reasons for HVAC differences.

DISCUSSION

The results of the OAT analysis provide a characterization of the effect of the modeler on simulation results under the conditions of the study. When substituted individually into the baseline model, the magnitude of the impact of participant decisions on the baseline model depended on a combination of the sensitivity of the model to



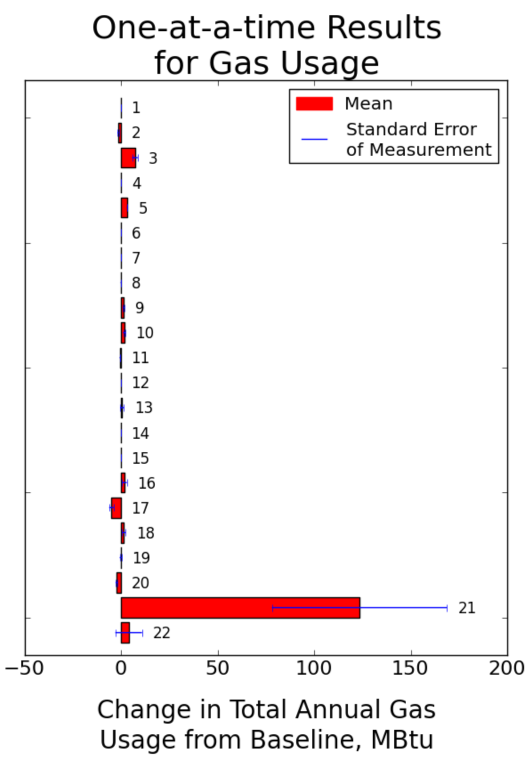


Figure 3: OAT results for electricity (top) and gas (bottom). Bars represent averages of the differences in total annual energy use from the baseline total annual energy use. Baseline annual energy use for electricity was 21786 kWh and for gas, 21 MBtu.

Table 4: OAT factors with corresponding reference numbers.

Ref.Num.	Factor
1	Site data
2	Exterior wall properties
3	Interior wall properties
4	Exterior lighting power
5	Domestic water heater properties
6	DHW loop
7	Zone type
8	Occupancy schedule
9	Lighting schedule
10	Equipment schedule
11	Infiltration schedule
12	Infiltration method
13	Infiltration rate
14	LHG (people)
15	SHG (people)
16	Lighting power
17	Equipment power
18	Number of people
19	Space and plenum height
20	Windows
21	HVAC
22	Original geometry

the participant inputs and on the tendency of the study population to make a given decision. Because modelers may be partially aware of the sensitivity of a model to various factors, the sensitivity of the model and the modeler decisions are intertwined.

Variation in participant modeling decisions can be grouped into the following categories: cases where the modeler was lacking information required by the model, cases where the information provided was complex and/or the method of presentation to the modeler and the method of input differed, and cases where the information was provided but the modelers did not know the importance of including the factor in the simulation results. There were also factors that involved complex input or where the modelers lacked information, but very little variation was seen between modeler decisions.

Modelers did not know occupancy, lighting, or equipment schedules when modeling the building; nor did they know occupancy rates or equipment power. The domestic hot water heater was indicated in plans, but the type was not indicated. Despite reasonable assumptions on the part of all modelers for lighting and equipment schedules and setting equipment power to recommended levels, large variation was seen in energy predictions between modeler decisions. Occupancy decisions had a minimal impact on this model, however. All participants included the domestic water heater (this piece of information was present), but all left the water heater at the default type, resulting in little variation between modelers in this factor.

Modelers had detailed information on exterior and interior lighting power, as well as HVAC equipment. They were also provided with all the elevation views, from which height measurements and window locations could be determined. However, all of these items of information were not provided in the format required for eQUEST inputs. Modelers consequently had to perform multiple calculations, estimates, and make judgments about the correct manner of interpreting building information for eQUEST input. As a result, high variation between modeler inputs were seen in lighting power and HVAC decisions, and many participants omitted exterior lighting altogether. Windows and building height caused little variation despite the extra effort required to measure, rather than read, the dimensions off of the plans.

In addition to difficulties with interpreting exterior lighting plans for inclusion in the eQUEST model, the decision of whether to include exterior lighting was left to participants. Some may have decided that the intention of the simulation was to assess energy interactions within the building, for which exterior lighting would not be relevant.

The inconsistent inputs (that is, errors) were infrequent and therefore had minimal impact on the aggregate energy results. The primary sources of modeler variability are:

(i) situations where modelers are not provided with specific input information (e.g. operating schedules, occupancy levels, and equipment power not being provided to the modeler),

(ii) differences between provided plan information and simulation program inputs (e.g. requiring exterior lighting input in power per total square foot vs. the total power being provided in the lighting plans, or eQUEST HVAC inputs asking for different efficiency ratings than those provided by the mechanical plans),

(iii) complexity of input methods (e.g. the methods in eQUEST for creating different heights for zones or putting in exhaust fans), and

(iv) a lack of clarity regarding the intended scope of the simulation study (e.g. whether the intent was to study the thermal performance of the building or to predict the total energy use).

FUTURE WORK

The research presented in this paper is part of only a small body of work focusing on the role the modeler plays in simulation program results. Additionally, much of the research on this topic is over a decade old and user interfaces for simulation programs have progressed during this time period. Research in this area should be expanded and should explore changes in the levels of modeler variation with updates to simulation programs. Modeler variability tests would simultaneously serve as assessments of the variability of a modeling population, establish the position of individuals within this range of modeler variability, and assess the propensity of a simulation program to cause modeler variability for a given input.

In addition, further study should include modelers in different climate zones and users of different simulation programs, and cover a range of building types. Testing procedures could be expanded to include having study subjects complete the modeling task in their normal work environment and providing them with unlimited time to complete the model. Research could also focus on individual aspects of modeling; a focused study on HVAC systems would be advisable due to the complexity of HVAC system inputs and the importance of HVAC to total energy use.

Future studies, particularly those with larger sample sizes, would benefit from using a simulation program that at minimum has a consistent input format (e.g. a CSV format) to facilitate automation of reading information from participant input files. Modeler studies would be further facilitated by the following features being developed for simulation programs:

- An easy method of identifying spaces across models. This could be automatically accomplished through identification of a reference point and an algorithm that calculates equivalent geometries, or it could be done manually, where a researcher identifies spaces as equivalent between files and the program updates variable names and dependencies in a consistent fashion.

- Easy extraction of data, with values in the original entry format (for evaluation of modeler decision making processes) and in a normalized form that can be directly substituted into a model with different geometry but produce results equivalent to the original model (e.g. data that are provided on a per area basis).

The results of this study indicated two main areas where the simulation process leads to modeler variability; methods of modifying simulation program workflows to reduce modeler variability are proposed:

- Modeler variability that occurs when there are large discrepancies between simulation program data entry methods and the format of data provided to modelers could be dealt with by providing alternate entry methods. Allowing the modeler to choose the entry method that corresponded with the format of the plans would reduce errors and calculations. It is additionally advisable to move towards the method of entry provided by the Building Component Library (Fleming, Long, and Swindler 2012) to reduce the complexity of entry for items such as HVAC systems. BES programs could additionally do a check of manually entered data (analogous to a spellcheck) that would look for values that varied by a factor of 10 or more from other values (in order to capture simple decimal or unit errors).

- In areas that are not well defined for buildings but that have high impact on energy predictions, modelers currently have to choose from a wide range of suggested values (particularly for equipment power) that are all equally legitimate. Their choice arbitrarily pins down a value in the range of variability; instead, they could choose the appropriate range and the simulation could propagate the variability accordingly. This approach could be a standardized input option for simulation programs and provide simulation end users with reasonable ranges on their expected energy use.

If any of the above recommendations are implemented into simulation programs, their results could be tested against previous results for the same simulation program. Successes in reducing modeler variability through simulation program modifications could lead to standards for Building Energy Simulation programs.

CONCLUSIONS

In aggregate, participant decisions caused a -11% to $+104\%$ variation in simulation results from the baseline model's predictions for electricity and a -61% to $+1535\%$ variation in gas predictions. The HVAC factor alone caused a $+34\%$ variation in electricity predictions from the baseline and a $+588\%$ variation in gas predictions, on average. The results of this research indicate that professional modelers, while still making reasonable modeling decisions, will have a significant effect on simulation results. Future research in modeler variability and simulation workflow modifications will better define modeler variability and lead to its reduction.

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REFERENCES

Ashrae. 2013. *2013 ASHRAE Handbook Fundamentals*.

Bloomfield, D.P. 1986. "The influence of the user on the results obtained from thermal simulation programs." *CIB 5th Int. Symp. On the use of computers for environmental engineering related to buildings*.

Bradley, David E, Michael Kummert, and Timothy P. McDowell. 2004. "Experiences with and interpretation of standard test methods of building energy analysis tools." *IBPSA-Canada Bi-Annual Conference, eSIM*. Vancouver: IBPSA.

Fleming, Katherine, Nicholas Long, and Alex Swindler. 2012. "The Building Component Library : An Online Repository to Facilitate Building Energy Model Creation." *ACEEE Summer Study on Energy Efficiency in Buildings*.

Guyon, Gilles. 1997. "Role of the model user in results obtained from simulation software program." *International Building Simulation Conference*. Prague: IPBSA, 377–384.

Ibarra, Diego I ., and Christoph F . Reinhart. 2009. "Daylight factor simulations - how close do simulation beginners really get?" *Building Simulation*. 196–203.

Title24. 2010. 2008 Building Energy Efficiency Standards for Residential and Nonresidential Buildings.