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Parametric Analysis of Building Elements on Building Energy Use

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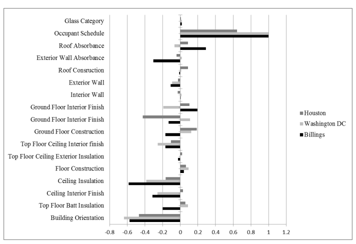
Graphical abstract



Abstract

Building energy modeling is essential to estimate energy consumption of buildings. Predicting building energy consumption benefits the owners, designers, and facility managers by enabling them to have an overview of building energy consumption and can help them to determine building energy performance during the design phase. This paper focuses on two different shapes of commercial building, H and rectangle to estimate energy consumption in buildings in three different climate zones, cold, hot-humid, and mixed-humid. To address this, DOE-2 building simulation software was used to build and simulate individual commercial building configurations that were generated using Monte Carlo simulation techniques. Ten thousand simulations for each building shape and climate zone were conducted to develop a comprehensive dataset covering the full range of design parameters.

Keywords: Building energy modeling; parametric design analysis; building shape

■1.0 INTRODUCTION

Forty percent of total U.S. energy is consumed in residential and commercial buildings and about half of that (18 Quadrillion Btu) is associated with commercial buildings [1]. Building energy consumption prediction is a complicated task because it depends on several factors such as building characteristics, energy system characteristics, control and maintenance, weather parameters, and behavior of occupants ([2], [3], and [4]). As buildings are getting more complex with higher performance, employing a simulation technique seems to become an integral part and a requirement during the design phase ([5], [6], and [7]). Building energy models have several benefits including, saving time to analyze, design, and optimize building energy performance during the design and operation phases, enhance accuracy of energy saving projections, and facilitate comparison of the cost-effectiveness of targeted energy-conservation measures (ECMs) ([8] and [9]). It is important to note that it is very difficult and challenging to have an accurate estimate of building energy consumption. Although several studies are conducted on energy simulation models, it is prudent to have a systematic method to unify and simplify all of the diverse approaches in building energy consumption. There are many studies conducted on building parameters and their effects on building energy performance. For example, Sattari and Farhanieh [10] had a parametric study on the performance of the radiant floor heating systems and Theodosiou [11] conducted a parametric study on green roofs. Aste *et al*. [12] conducted a parametric study on the efficiency of the thermal inertia while Kumar and Kaushik [13] studied planted roof parameters and properties. This paper provides a simple and realistic approach to estimate energy consumption of a typical office building in three different locations and climate zones. The locations include: Billings, MT (6A) - cold, Houston, TX (2A) - hot-humid, and Washington DC (4A) - mixed-humid [14]. These climate zones were selected to compare the annual energy consumption of H-shape and rectangle office buildings and the effect of different parameters in energy performance of these two typical office building types.

■2.0 BUILDING ENERGY MODELING

Building energy simulation techniques provide a unique opportunity for MEP (Mechanical, Electrical, and Plumping) designers to review building energy consumption and optimize the building design during the feasibility study of construction projects. USGBC (U.S. Green Building Council) that developed LEED (Leadership in Energy and Environmental Design) provides 1 to 19 points for the whole building energy simulation [15]. The points are allocated to the building based on the percentage of improvement in building performance. The improvement is measured in comparison with baseline building performance ASHRAE Standard 90.1-2007 [16]. The main purpose of simulation modeling is to allow the designers to review building energy consumption and enable them to select ECMs that meet the goal of owners on how much energy want to save. Based on analysis of available tools and programs, DOE-2 software was selected to model building energy consumption for each building shape. The Monte Carlo Simulation uniform probability distribution was employed for each variable and 10,000 simulations were run in both building shapes in three climate zones. Python programming language was used to develop a numerical code interfacing DOE-2 to extract useful data and be able to conduct multiple linear regression analysis to model the relationship between different parameters and annual energy consumption. The constant parameters for DOE-2 inputs as well as variables for the Monte Carlo simulation are used from reference [2]. The properties of building components were defined and set of ranges and values are employed from AHRAE Standard 90.1 [16]. The steps are taken in this study is illustrated in Figure 1.

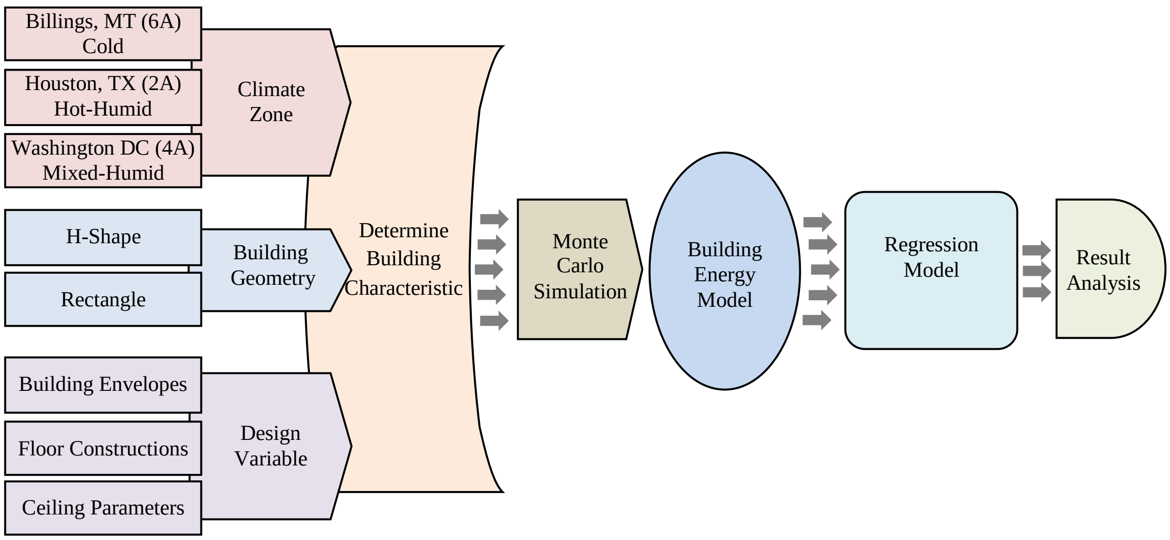


Figure 1 The steps taken in parametric analysis of building energy use

■3.0 RESULT AND DISCUSSION

Building energy consumption is dependent on several internal and external factors. In this study the standardized regression coefficients are used in both H-shape and rectangular commercial buildings in three different climate zones to understand the effect of building parameters on annual energy consumption. Parametric study helps to determine the effectiveness of building parameters on annual energy consumption. Annual energy consumption of three different climate zones in H-shape and rectangle commercial buildings is shown in Figure 2 which shows that H-shape buildings, in all of the three climate zones have higher annual energy consumption because of more surface exterior areas. In addition, Billings with cold winters and hot summers consume more energy in comparison with Washington DC (mixed-humid) and Houston (hot-humid). Regression equations were developed according to the different shapes of a commercial building (H-shape and rectangle) in different climate zones using a total of seventeen main building design factors to simulate different design scenarios. Regression equations related to each building shape and climate zone are shown in Table 3.

To determine feasibility and accuracy of regression models, different set of dependent variables were used and the generated random numbers in Monte Carlo simulations were divided into two groups (80% for training and 20% for evaluation of model accuracy). The annual energy consumption based on DOE-2 program and regression models for rectangle buildings in the three different climate zones (cold, hot-humid, mixed-humid) for a similar design and operation is shown in Figure 3. The results from the models are in the acceptable range of errors with less than 5%. The standardized regression coefficients are used as a quantitative measure to understand the impact of different parameters in energy consumption of both H-shape and rectangle geometries. Building orientation and occupant schedule had the most impact on energy consumption in H-shape commercial building in all the three weather conditions (Figure 4) while occupant schedule had the largest effect on energy consumption of rectangle office buildings (Figure 5).

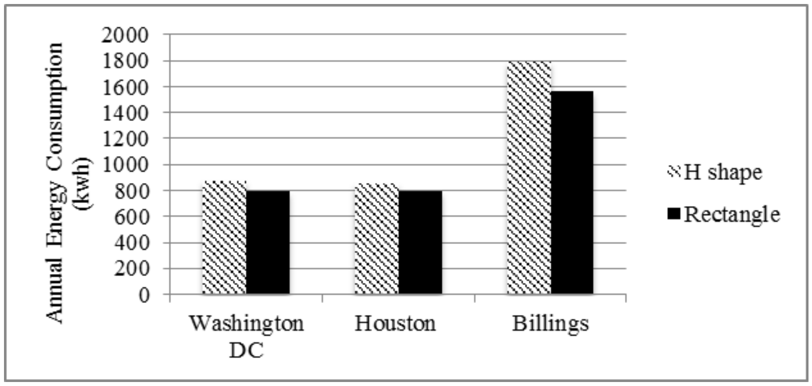


Figure 2 Annual energy consumption in H-shape and rectangle building shapes

Table 3 Regression equations related to H-shape and rectangle buildings in there climate zones

Regression coefficient	$y = \beta x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_5 + \beta_6 x_6 + \beta_7 x_7 + \beta_8 x_8 + \beta_9 x_9 + \beta_{10} x_{10} + \beta_{11} x_{11} + \beta_{12} x_{12} + \beta_{13} x_{13} + \beta_{14} x_{14} + \beta_{15} x_{15} + \beta_{16} x_{16} + \beta_{17} x_{17}$					
	H-shape			Rectangle		
	Washington DC	Houston	Billing	Washington DC	Houston	Billing
β_1	-8.78	-8.07	-10.02	-0.68	1.67	-2.09
β_2	1.21	1.02	-3.46	0.70	1.19	-3.52
β_3	-3.57	0.51	-5.49	-3.16	0.49	-5.01
β_4	-5.30	-2.84	-10.17	-4.14	-1.61	-8.92
β_5	1.28	1.12	0.73	1.01	0.72	0.49
β_6	-0.09	0.33	-0.46	-0.10	0.31	-0.42
β_7	-3.53	-1.85	-2.94	-3.39	-1.78	-2.93
β_8	1.70	3.21	-2.92	1.41	2.55	-2.78
β_9	1.51	-7.34	-2.29	1.90	7.03	-1.57
β_{10}	-2.65	1.80	3.39	-2.83	2.65	2.25
β_{11}	0.20	-0.48	0.08	0.41	-0.10	0.21
β_{12}	-1.25	-0.41	-1.90	-0.88	-0.32	-1.32
β_{13}	0.17	1.53	-0.24	0.08	1.30	-0.29
β_{14}	0.22	-0.23	-5.29	-0.01	-0.98	-4.45
β_{15}	-0.90	1.51	5.03	-1.47	1.514	3.24
β_{16}	13.80	11.12	17.40	12.65	9.79	15.66
β_{17}	0.25	0.10	0.31	0.27	0.15	0.290
R^2	0.95	0.95	0.94	0.94	0.95	0.94
F-test	8980	9119	8791	868	918	862

x_1 = building orientation, x_2 = top floor Batt insulation, x_3 = ceiling interior finish, x_4 = ceiling insulation, x_5 = floor construction, x_6 = top floor ceiling exterior insulation, x_7 = top floor ceiling interior finish, x_8 = ground floor construction, x_9 = ground floor Interior finish, x_{10} = floor interior finish, x_{11} = interior wall, x_{12} = exterior wall, x_{13} = roof absorbance, x_{14} = exterior wall absorbance, x_{15} = roof absorbance, x_{16} = occupant schedule, x_{17} = glass category.

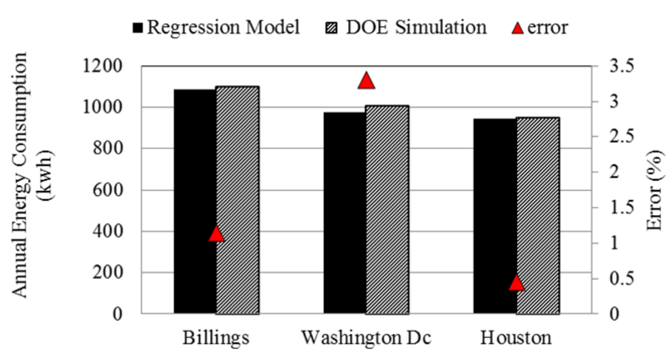


Figure 3 Regression model validation for rectangle buildings in three different climate zones

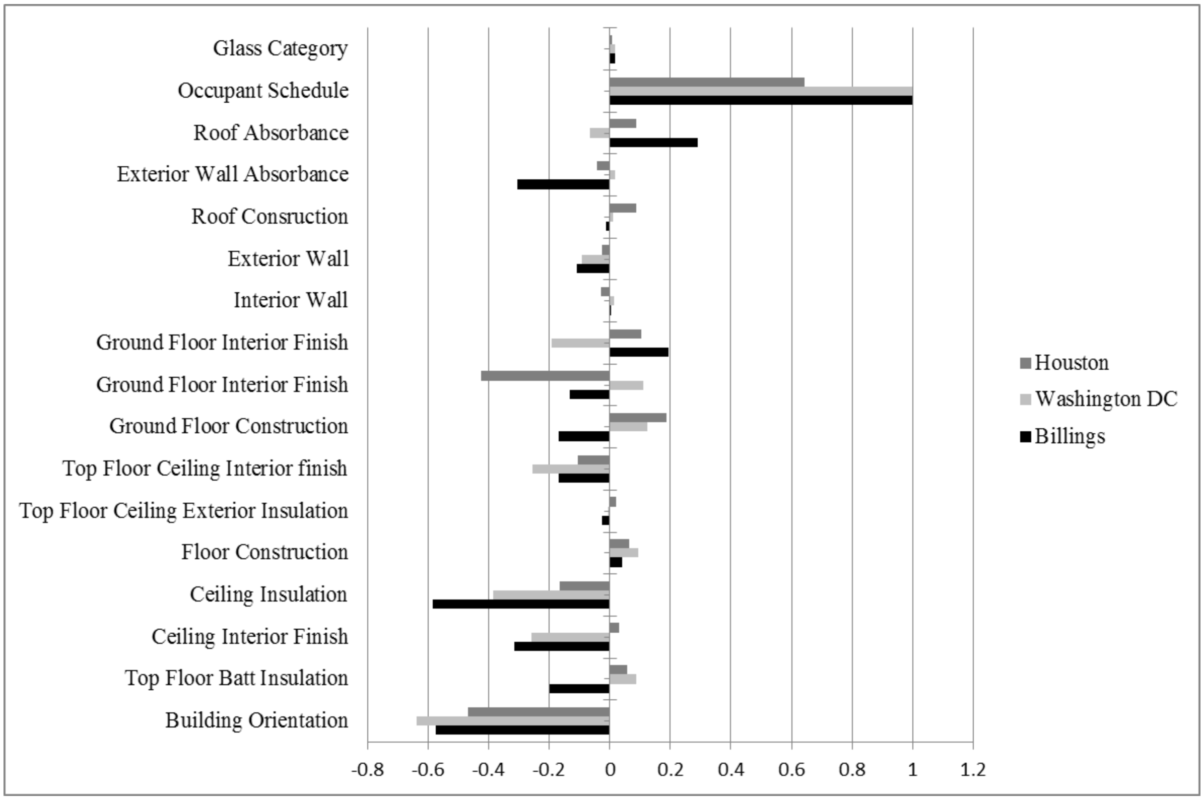


Figure 4 Effect of building parameters on annual energy consumption in H-shape commercial buildings

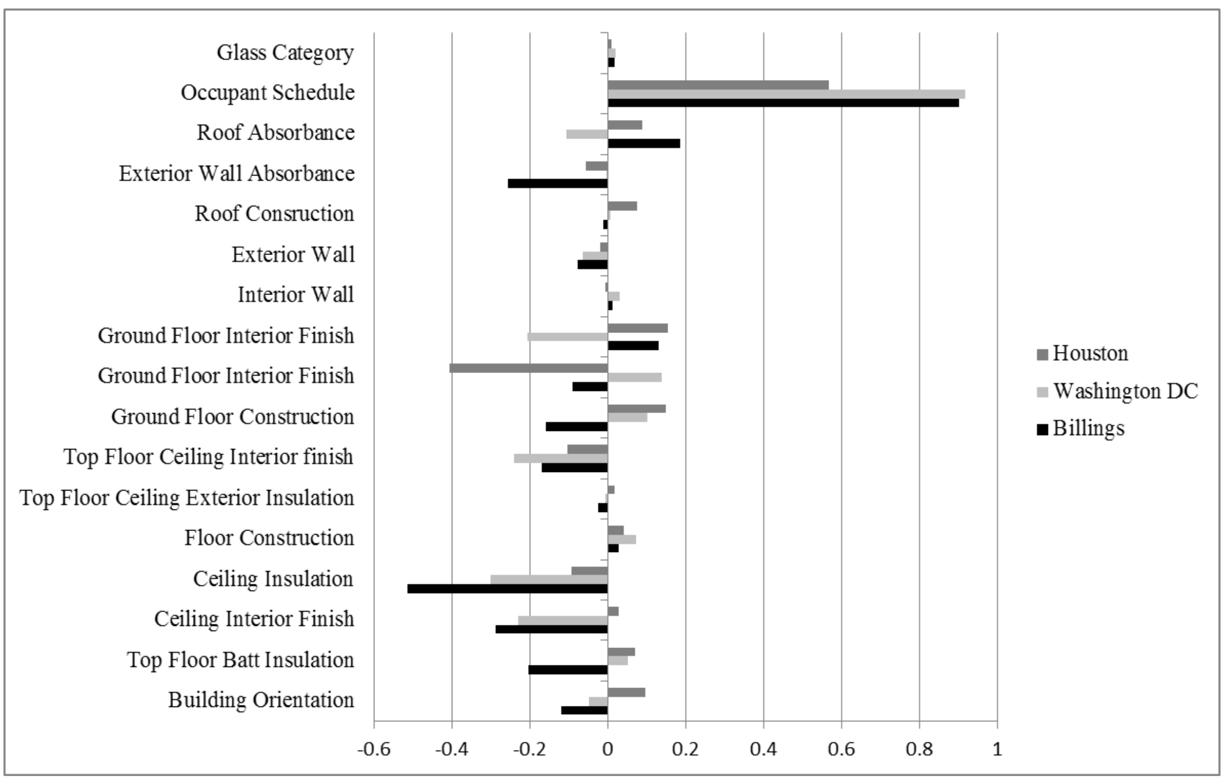


Figure 5 Effect of building parameters on annual energy consumption in rectangle shape commercial buildings

4.0 CONCLUSIONS

In this study, seventeen variables were considered in two different building shapes (H-shape and rectangular) in three climate zones (cold, hot-humid, mixed-humid) as the inputs for regression models. The results from the models are in the acceptable range of errors with less than 5%. Occupant schedule in both H-shape and rectangle and building orientation in H-shape commercial buildings in all the three climate zones had the most effect on energy consumption. The developed models in this paper provide an opportunity for MEP designers, owners, and facility managers to estimate energy consumption of the commercial office buildings at the earliest phase of the construction projects. It enables them to select energy consumption measures according to the goal of the project for saving energy.

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